Great Lives from History

Inventors & Inventions

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Volume 1
ʿAbbas ibn Firnas - Philip Emeagwali

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PUBLISHER'S NOTE

Great Lives from History: Inventors and Inventions (4 vols.) joins the *Great Lives* series, which provides in-depth critical essays on important men and women in all areas of achievement, from around the world and throughout history. The series was initiated in 2004 with *The Ancient World, Prehistory-476 C.E.* (2 vols.) and followed in 2005 by *The Middle Ages, 477-1453* (2 vols.) and *The Renaissance and Early Modern Era, 1454-1600* (2 vols.); in 2006 by *The 17th Century, 1601-1700* (2 vols.) and *The 18th Century, 1701-1800* (2 vols.); in 2007 by *The 19th Century, 1801-1900* (4 vols.) and *Notorious Lives* (3 vols.); and in 2008 by *The 20th Century* (10 vols.). With this new installment, the entire series extends to 31 volumes, covering 4,885 lives.

SCOPE OF COVERAGE

Great Lives from History: Inventors and Inventions features 409 essays covering 413 individual inventors (including 27 women) from all time, worldwide. All essays were written specifically for this new publication. The editors have included in this set those inventors recognized for shaping modern technology and the way we live today—coverage that is essential in any liberal arts curriculum. The editor's criteria for including these individuals in this publication took into account their fame as inventors, the significance of their inventions, the amount of time they spent inventing, their representation of world inventors, their relevance to class curricula, and their interest to high school, undergraduate, and general readers.

For purposes of this publication, the term "invention" was defined to include not only mechanical and other physical devices but also processes (e.g., the Bessemer process for making steel), software (such as Grace Hopper's invention of COBOL), and systems such as those applied to business management. Pure scientific theories (such as laws of physics) were excluded, although rare exceptions were made for such systems and tools that have had a comprehensive influence on our way of interacting with the world, such as Aristotle's invention of the first system of biological taxonomy, Newton's creation of the calculus, and Einstein's theories of relativity.

By category, the contents include persons whose inventions fall into one or more of the following areas: acoustical engineering (2), aeronautics and aerospace technology (32), agriculture (13), architecture (6), astronomy (15), automotive technology (16), biology (14), business management (12), cartography (1), chemistry (59), civil engineering (12), communications (31), computer science (36), electronics and electrical engineering (88), entertainment (3), fire science (1), food processing (6), genetics (6), geography (2), geology (2), horticulture (1), household products (21), industrial technology (3), manufacturing (40), maritime technology (3), mathematics (25), mechanical engineering (42), medicine and medical technology (34), military technology and weaponry (33), music (9), naval engineering (9), navigation (7), oceanography (1), optics (14), packaging (3), photography (9), physics (104), plumbing (1), printing (7), and railway engineering (8).

The inventors covered in these volumes are also identified with one or more of the following countries or regions: Australia (2), Austria (1), Belgium (4), Canada (11), China (3), Croatia (2), Czech Republic (1), Egypt (3), England (46), Estonia (1), France (20), Germany (39), Greece (2), Hungary (3), India (2), Iran (1), Ireland (3), Israel (1), Italy (9), Japan (4), Netherlands (9), Nigeria (1), Northern Ireland (2), Poland (2), Russia (8), Scotland (15), Sicily (1), Spain (1), Suriname (1), Sweden (5), Switzerland (5), Turkey (1), United Kingdom (63), United States (246), Uzbekistan (1), and Wales (1).

ESSAY LENGTH AND FORMAT

Each essay is from 2,000 to 2,500 words in length (roughly 3 to 4 pages) and displays standard ready-reference top matter offering easy access to following biographical information:

- The essay title is the name of the individual as best known.
- The individual's nationality and occupation follow on the second line (e.g., Japanese physicist).
- A summary paragraph highlighting the individual's historical importance in relation to his or her inventions indicates why the person is studied today.
- The *Born* and *Died* lines list the most complete dates of birth and death available, followed by the most precise locations available, as well as an indication of when these are unknown, only probable, or only approximate; both contemporary and modern place-names (where different) are listed. A question mark (?) is appended to a

date or place if the information is considered likely to be the precise date or place but remains in question. A "c." denotes circa and indicates that historians have only enough information to place the date of birth or death near the year listed. When a range of dates is provided for birth or death, historians are relatively certain that the birth or death year could not have occurred outside the date range.

- *Also known as* lists other versions of the individual's name, including full names, given names, alternative spellings, pseudonyms, and nicknames.
- *Primary fields* lists all categories of invention, from Acoustical Engineering through Railway Engineering.
- *Primary inventions* lists the inventions for which the inventor is best known.

The body of each essay, which also includes a byline for the contributing writer-scholar, is divided into the following three parts:

- *Early Life* provides facts about the individual's upbringing and the environment in which he or she was reared, as well as the pronunciation of his or her name (if unfamiliar to English speakers). Where little is known about the person's early life, historical context is provided.
- *Life's Work*, the heart of the essay, consists of a straightforward, generally chronological, account of the period during which the individual's most significant achievements were accomplished.
- *Impact* is an overview of the individual's place in history, particularly as his or her inventions changed the way we live.

The end matter of each essay includes the following resources:

- *Further Reading*—annotated bibliography, a starting point for further research.
- *See also*—lists cross-references to essays in the set covering other inventors of interest.

SPECIAL FEATURES

Several features distinguish this series as a whole from other biographical reference works. The front matter includes the following aids:

- *Key to Pronunciation:* A key to in-text pronunciation of unfamiliar names appears in all volumes. Pronunciation guidelines for difficult-to-pronounce names are provided in the first paragraph of the essay's "Early Life" section.
- *Complete List of Contents:* This alphabetical list of contents appears in all four volumes.
- *List of Inventions:* This is an index of all the major inventions covered, showing the inventor in parentheses.
- *Sidebars:* A key feature of every essay in this publication is a sidebar on one of the inventor's most important inventions, which appears in a shaded box beside the biography.

The back matter to Volume 4 includes several appendixes and indexes:

- *History of U.S. Patent Law:* an essay discussing patent law in the United States
- *Chronological List of Entries:* inventors covered, arranged by birth year
- *Time Line*
- *Biographical Directory of Inventors:* an annotated listing of inventors that goes beyond the coverage in the essays
- *Electronic Resources*
- *Bibliography*

Finally, volume 4 ends with three useful indexes:

- *Category Index:* entries by area of achievement, from Acoustical Engineering through Railway Engineering
- *Geographical Index:* entries by country or region
- *Subject Index:* a comprehensive index including personages, inventions, concepts, technologies, terms, principles, and other topics of discussion, with full cross-references from alternative spellings and to the category and geographical indexes

CONTRIBUTORS

Salem Press would like to extend its appreciation to all involved in the development and production of this work. The essays have been written and signed by scholars of history, the sciences, and other disciplines related to the essays' topics.

Special thanks go to Alvin K. Benson, Professor of Physics at Utah Valley University, who developed the contents list and coverage notes for contributing writers to ensure the set's relevance to high school and undergraduate curricula. Professor Benson served as a Professor of Physics in the Indiana University system from 1972 to 1978; from 1978 to 1986 he worked in research and development for Conoco, Inc. and DuPont; and from 1986 to 2001 he was a Professor of Geophysics at Brigham Young University, retiring in September, 2001. He has authored or coauthored more than four hundred research articles, three books on geophysics, and a CD-ROM on geophysics, and he is the recipient of the Honorary Bausch and Lomb Award, Outstanding Young Man of America Award, Alcuin Teaching and Research Award, Distinguished Leadership Award, a Citation of Meritorious Achievement in geophysical research, Professor of the Year in the BYU College of Physical and Mathematical Sciences, Best Paper Award in the Physical Sciences from The Utah Academy of Sciences, Arts, and Letters (2005), and the Faculty Excellence Award in the UVSC School of Science and Health (2006).

Without all these expert contributions, a project of this nature would not be possible. A full list of the contributors' names and affiliations appears in the front matter of this volume.

EDITOR'S INTRODUCTION

Great Lives from History: Inventors and Inventions concentrates on inventors who centered much of their lives on the inventive process and whose inventions have raised the human standard of living. Emphasis is placed not only on the inventors' biographies but also on the stories behind their inventions: the forces and circumstances motivating them and the impact that their inventive genius and resulting inventions have had on humankind. Inventors were chosen based on whether their inventions have had an impact on the world in one or more of the following ways:

- by changing the way people work and play, contributing to the improvement of life
- by altering culture and society for the better
- by saving lives and extending longevity
- by helping to eliminate boring, hard work
- by teaching important principles and creativity
- by advancing science and technology
- by standing the test of time, being used by many people over generations.

Inventions range from tangible mechanical or other physical devices to mechanical and chemical processes. Each essay sheds light on the inventive process, the hard work, the numerous dead ends, and the successes that the inventors encountered.

Inventors and Inventions focuses on the lives of inventors who fostered an idea for something that did not exist until they made it happen, as contrasted to discoverers who found something inherent in nature that was always there just waiting to be brought to light, such as Alexander Fleming's discovery of penicillin in 1928. Nylon involved both a discovery and an invention. Using the discovery of the chemical structure of silk fibroin and cellulose, Wallace Hume Carothers invented synthetic nylon. Except for rare and very important instances, pure scientific theories and mathematical formulations are not included, and except for a few cases, innovators—those who moved an invention into a commercial mode—are likewise not included in this work. Most innovators have not been inventors. Some inventors have also been innovators, but most have not. For example, Theodore Harold Maiman not only invented the first operable laser but also established the scientific environment and business structure that led to its numerous applications and commercial success.

Inventors and their inventions provide a window on history that parallels the story of human progress and corresponds to the cultural revolutions that have impacted the world. Although inventions are not distributed evenly over time, they have for the most part developed systematically as dictated by human need or desire for improvement. Early inventions centered around the necessities of life, particularly farming, housing, and clothing. After the Middle Ages, the emphasis shifted to literacy and numerical skills. Johann Gutenberg's invention of the metal movable-type printing press was the foundation for the "learning revolution," as books became cheap and were made available to the general public. During the 1700's, the focus on inventions moved to devices and processes that increased the ease and efficiency with which human tasks could be accomplished. The invention of the steam engine fueled the Industrial Revolution. During the latter part of the nineteenth century, electricity was harnessed for practical usage. Invention of devices that could use electricity in the everyday world sparked the "communication revolution." In the twentieth century, more and more inventions were made using a systematic scientific approach in industrial research laboratories, research universities, and government laboratories. Inventions that include microelectronics, computers, telecommunications, robotics, and synthetic materials unleashed the "digital revolution" that led to the emergence of the World Wide Web, as inventors and their inventions concentrated increasingly on global connectedness. Included in *Great Lives from History: Inventors and Inventions* are the important inventors whose inventions span a diverse range of disciplines and who helped to spearhead and develop the learning, industrial, communication, and digital revolutions that dramatically changed and shaped the world.

Great Lives from History: Inventors and Inventions includes inventors from all time periods of human history, ancient to modern, and from all parts of the world, including many from thinly represented areas of the world. During ancient times, inventive prominence was centered in China, Egypt, and the Euphrates River Valley, then moved to Greece and Rome, then to the Islamic world, then to Europe, and finally to America. The oldest known wheel can be traced to Mesopotamia and is believed to date back more than 5,000 years ago. The invention of the papermaking process is attributed to Cai Lun in China around 105 C.E. Roger Bacon, an English medieval inventor, was one of the first Europeans to formulate the scientific method based on experimentation around 1250. Italian Leonardo da Vinci developed designs for the first flying machines in 1492. The first refracting telescope was assembled by Hans Lippershey in Holland in 1608.

The Industrial Revolution and the modern world emerged in large part as a result of post-Renaissance engineering, such as the invention of the first steam engine by Englishman Thomas Savery, around 1698. The development of steam power eventually revolutionized transportation, trade, and manufacturing, which in turn drove markets for other technologies. In 1793 Eli Whitney's cotton gin transformed the American South both economically and socially, making the United States the world's major supplier of cotton by the middle of the nineteenth century, which served to establish a growing foundation for slavery. A number of European and American inventors were involved with the invention and improvement of the sewing machine between 1790 and 1840. In 1857, Sir Henry Bessemer patented the process for making steel in England. The telephone was patented in 1876 in the United States by Alexander Graham Bell. As it is known today, the electric light was invented simultaneously in 1879 by Thomas Alva Edison in the United States and Joseph Wilson Swan in England.

One of the most impactful inventions of the past century and a half was the automobile. The automobile that was being produced by around 1900 evolved from a series of automotive inventions made by Nicolas-Joseph Cugnot and Étienne Lenoir in France, Nikolaus August Otto, Gottlieb Daimler, and Carl Benz in Germany, and Ransom Eli Olds, Henry Ford, and others in the United States. Like so many inventions before it, the automobile transformed the world not only economically but also socially. Home and work became geographically divided, teenagers took to the road and achieved a sometimes ill-advised independence, and Ford's assembly line transformed labor.

The great economic and social transformations of the twentieth century were grounded in the development of electricity in the nineteenth century. After innovators like Arthur James Arnot and Edison set the stage for the electric grid, night lighting extended productivity and telecommunications boomed. Well before Bell's invention of the telephone, English mathematician Charles Babbage laid the groundwork for the computer age by inventing the "difference machine" in the early nineteenth century, spending his life and fortune to develop this prototype of the digital computer. In 1946, the first fully electronic digital computer was invented by John Presper Eckert and John William Mauchly in the United States. With the invention of the World Wide Web protocol and language by Englishman Timothy Berners-Lee in 1990, the Internet emerged and eventually evolved into the dominant communications medium throughout the world.

In numerous instances, the names of the first inventors of many inventions are hard to find or have unfortunately been lost over time. The inventors of the first wheel, the first plow, the first compass, or the first smelting furnace, as well as the inventors of many other very important early inventions, remain unknown. Some inventions have involved the interaction and contributions of many people during their formulation, development, improvement, perfection, and implementation. Some have involved coinventors. In several such cases, the leading inventor is discussed in detail in this work, while the coinventor is discussed in the entry dealing with the main inventor. In some instances, there has been overlap of ideas and rival claims for the same invention. For example, Lenoir, Benz, Daimler, and Otto all have legitimate claims associated with the invention of the automobile that is powered by an internal combustion engine. Likewise, Ernst Alexanderson, Philo Farnsworth, and Vladimir Zworykin all have claims related to the invention of the television. These stories are captured and the claims sorted out in *Great Lives from History: Inventors and Inventions*.

Many of the inventors in these pages have been Nobel Prize winners. Several, including Alexander Graham Bell, George Washington Carver, Thomas Alva Edison, Nikola Tesla, and Alfred Nobel, have also been inducted into the National Inventors Hall of Fame, a nonprofit organization in the United States dedicated to recognizing, honoring, and encouraging invention and creativity. Special effort has been made to include female inventors, inventors from ethnic minority groups, and inventors who are often overlooked and almost never found in history books. Many of these inventors overcame great odds that were associated with discrimination and poverty to make important contributions through their remarkable creative abilities. Some inventors made useful inventions but otherwise left little trace in history. Thousands of inventors—too many to cover in depth within these four volumes—have made a broad range of useful and sometimes vital contributions to the progress of humankind. An appendix to this work, a "Biographical Directory of Inventors," is therefore included in volume 4. It offers not only a summation of the 413 individuals covered in the essays but 598 others as well.

Great Lives from History: Inventors and Inventions is written to engage high school students and to be wide-ranging, relevant, and interesting enough to appeal to undergraduates and to anyone interested in the history of technology. It is a tribute to human ingenuity and inventiveness that engenders an understanding of the conditions that can lead to useful inventions, as well as providing the necessary guidelines and role models to assist and inspire future inventors. A central theme included in every essay throughout this work is a concentration on the process of invention by means of a sidebar that highlights one of the inventor's most important inventions. This process involves the fermentation of ideas, attempts to implement the ideas, and the ultimate culmination of ideas that led to practical inventions and applications. It is hoped that the personal stories of the world's greatest inventors contained in this work, who have helped transform our homes, health care, work, environment, travel, and communication, will generate insights into the inventive process that will create curiosity and excitement within the reader. The vision, creativity, and persistence of the included inventors, who often faced great challenges in their lives, provides inspiration for anyone who is motivated to succeed in life and encourages future inventors to follow in their footsteps by producing devices and processes that will change and shape the world for the better. Annotated bibliographic entries for each essay in a "Further Reading" section, as well as cross-references to other inventors of interest, will help the interested readers to further their research interests and inventive pursuits.

Thanks are due to the many contributing authors for their diligence, expertise, literary skill, and cooperation in writing the essays for these four volumes. I also wish to express my deep, heartfelt thanks to my lovely, devoted wife, Connie Lynn, and to our loving family, whose encouragement and forbearance have been a constant influence throughout this project.

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KEY TO PRONUNCIATION

Many of the names of personages covered in *Great Lives from History: Inventors and Inventions* may be unfamiliar to students and general readers. For these unfamiliar names, guides to pronunciation have been provided upon first mention of the names in the text. These guidelines do not purport to achieve the subtleties of the languages in question but will offer readers a rough equivalent of how English speakers may approximate the proper pronunciation.

Vowel Sounds

Symbol	**Spelled (Pronounced)**
a	answer (AN-suhr), laugh (laf), sample (SAM-puhl), that (that)
ah	father (FAH-thur), hospital (HAHS-pih-tuhl)
aw	awful (AW-fuhl), caught (kawt)
ay	blaze (blayz), fade (fayd), waiter (WAYT-ur), weigh (way)
eh	bed (behd), head (hehd), said (sehd)
ee	believe (bee-LEEV), cedar (SEE-dur), leader (LEED-ur), liter (LEE-tur)
ew	boot (bewt), lose (lewz)
i	buy (bi), height (hit), lie (li), surprise (sur-PRIZ)
ih	bitter (BIH-tur), pill (pihl)
o	cotton (KO-tuhn), hot (hot)
oh	below (bee-LOH), coat (koht), note (noht), wholesome (HOHL-suhm)
oo	good (good), look (look)
ow	couch (kowch), how (how)
oy	boy (boy), coin (koyn)
uh	about (uh-BOWT), butter (BUH-tuhr), enough (ee-NUHF), other (UH-thur)

Consonant Sounds

Symbol	**Spelled (Pronounced)**
ch	beach (beech), chimp (chihmp)
g	beg (behg), disguise (dihs-GIZ), get (geht)
j	digit (DIH-juht), edge (ehj), jet (jeht)
k	cat (kat), kitten (KIH-tuhn), hex (hehks)
s	cellar (SEHL-ur), save (sayv), scent (sehnt)
sh	champagne (sham-PAYN), issue (IH-shew), shop (shop)
ur	birth (burth), disturb (dihs-TURB), earth (urth), letter (LEH-tur)
y	useful (YEWS-fuhl), young (yuhng)
z	business (BIHZ-nehs), zest (zehst)
zh	vision (VIH-zhuhn)

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ʿABBAS IBN FIRNAS

Spanish Arabic engineer

A Renaissance figure at the height of the Islamic golden age in Moorish Spain, ibn Firnas is most remembered for his revolutionary design of a glider, the first manually manipulated flying machine, and for executing the first recorded controlled flight.

Born: 810; Izn-Rand Onda, al-Andalus (now Ronda, Andalucia, Spain)
Died: 887; Córdoba, Spain
Also known as: ʿAbbas Qasim ibn Firnas (full name); Armen Firman
Primary fields: Aeronautics and aerospace technology; astronomy; mathematics
Primary invention: Glider

EARLY LIFE

That anything is known of ʿAbbas ibn Firnas (AH-bahs IHB-n FUR-nahz) is remarkable. Much in the archival records and libraries of the Islamic empire that evolved in the Iberian Peninsula across nearly seven centuries was systematically destroyed in the fifteenth century as part of the fierce religious wars that marked the closing century of the Muslim presence in Europe. Ibn Firnas was born in 810 in Izn-Rand Onda in al-Andalus, just over a century after nomadic Muslim invaders, specifically the Umayyad (modern-day Sunni Muslims), had begun to occupy what is contemporary Spain and Portugal after a fierce seven-year war. In the decades before ibn Firnas was born, tensions between East and West had largely severed the Muslim empire into two de facto independent cultural centers—one based far to the east around Baghdad, the other around the courts of Córdoba. With its military occupation under control by mid-century, the caliphate of Córdoba, under Abd al-Rahman II (who assumed the throne in 852), began an ambitious agenda that envisioned establishing the court as the leading cultural and scientific center of the civilized world, rivaling Baghdad, by attracting with huge sums of money the best Muslim minds and undertaking an ambitious program of public building and funding scientific and artistic endeavors.

It was to that court that ibn Firnas journeyed in his late thirties, most likely in his capacity as an accomplished musician and noted poet. It is conjecture, of course, but given the wide-ranging projects that ibn Firnas undertook upon arriving at the court and the scope of his scientific endeavors (he was proficient in chemistry, physics, astronomy, mathematics, and geology), his early education in the sciences must have been considerable or he was undoubtedly the most accomplished autodidact before Leonardo da Vinci.

LIFE'S WORK

Public records of ibn Firnas's achievements after establishing his presence at the court in Córdoba are far more reliable. In addition to his study of flight, ibn Firnas distinguished himself in the realms of astronomy and geology. In an era when clocks were used not to measure the hour so much as to measure astronomical movements and particularly the Sun's position, ibn Firnas designed a kind of grand water clock that drew on a steady stream of running water to create an accurate system of measuring the Sun's movement by relying on a waterwheel and chain drive.

Given the enormous geological riches of the Iberian Peninsula, specifically its crystal quartz reserves, the potential economic boom was frustrated because the Córdoba court had to rely on exporting the crystals, principally to Egypt, known at the time for its techniques of cutting crystals. Ibn Firnas devised a revolutionary system for cutting crystal that virtually eliminated the inconvenience and the expenses of exporting the rock. In addition, he experimented with ways to convert the abundant sand and stone of the region into crude optical glass.

Distracted by the often elaborate theorizing about the workings of the planets and the movement of the stars, ibn Firnas devised a precursor to the modern planetarium, an elaborate hanging system of interlocked rings that displayed (with the help of a hand-turned crank) planetary motions with remarkably accurate scale (this nearly seven centuries before Nicolaus Copernicus). That device gave theoretical astronomers the opportunity to test early hypotheses about the relationship between orbit and planet size and the effects of stars on heavy planet motion. Later, ibn Firnas devised a similar surrounding experimental environment that re-created with apparently mesmerizing effect the meteorological phenomena of clouds, thunder, and lightning (through cleverly concealed devices) and gave audiences breathtaking images of stars.

It was flight, however, that drew ibn Firnas in his later years. Ibn Firnas witnessed an attempt at flight in 852, when a court daredevil, using a gaudy winglike overcoat that worked less as a flying device than as a parachute, leaped amid a carnival-like atmosphere off a minaret tower in Córdoba. Ibn Firnas studied flight for nearly two decades before attempting his own flight in 875. Unlike that earlier flight, ibn Firnas envisioned controlling the flight and sustaining it beyond a slightly delayed fall. To that end, he designed a rudimentary one-person glider. Records of invited eyewitnesses indicate that ibn Firnas covered himself with a feather-suit and attached to himself a pair of winglike devices, wooden frames that mimicked the bone structure of wings and that were themselves strung with feathers. He launched himself from a considerable height, from the Mount of the Bride, a steep natural promontory outside Córdoba. Fortunately for ibn Firnas, or perhaps through his own calculations, his launch position was favorable to an extended flight: From the promontory, the hill sloped into a rather deep valley, thus providing sufficient updraft to keep the glider in air, which it did for nearly ten minutes. However, after navigating the device and actually returning to the point of his departure—thus accomplishing the first controlled flight—ibn Firnas had difficulty in the landing and essentially crashed, seriously injuring his back (he was in his mid-sixties at the time). Although he continued other scientific endeavors for nearly a decade after his storied flight, he never tried flight again. He died in 887 at the age of seventy-seven.

THE GLIDER

Because experimental notes and laboratory logs that might detail ʿAbbas ibn Firnas's speculative process in designing his flight mechanism have never been recovered, contemporary aeronautic design engineers, interested in explicating how ibn Firnas achieved controlled flight for an extended period of time, begin with ibn Firnas's observation of a botched flight in 852. That flight device lacked any way for the pilot-rider to actually control the arc and trajectory of the flight and made inevitable a difficult and potentially life-threatening landing. Indeed, eyewitness accounts describe it as a breathtaking free fall rather than a flight. Ibn Firnas's glider, on the other hand, permitted him to change altitude and even bank and change the direction of his flight path.

Because eyewitness accounts describe ibn Firnas's device as "winglike," contemporary engineers assume that ibn Firnas studied the gliding flight of birds to design his glider. Given the extended period of his flight—nearly ten minutes—it is conjectured that his wing-style device, most likely strapped to his shoulders, must have been in the range of eight feet across, as wing length is crucial to achieving ascent. Generally, the wider the wing angle, the greater the lift. Ibn Firnas's device did not have a motor, nor did the wings flap. Thus, aeronautical engineers conclude that ibn Firnas essentially created not a flying machine but a glider. Some species of birds can glide for extended periods of time. That power comes not from the wings but from taking advantage of thermals—sharp, upward movements of air heated by the Sun as the day progresses. (Ibn Firnas took his flight late in the day.) Thermals rise off the Earth in layers that in turn save the birds tremendous amounts of energy and permit extended hovering. Birds actually float down on thermals. In this, ibn Firnas chose a high elevation and a valley slope to assist his gliding; such topography creates strong updrafts.

The problem came in ibn Firnas's landing. A glider must end its flight slowly. To land, a bird slows its wing beats and slowly lifts its wings at the shoulders even as gravity begins to pull it downward. It has to twist its tail to increase the surface area of the wing, which in turn generates more lift and slows down the landing like a brake, preventing the bird from dropping too fast. It is basically a controlled stall maneuver. Then the tail is spread open and lowered to execute a clean landing. A bird actually lands on its tail. Ibn Firnas's device had no tail apparatus, and thus his landing was quite difficult and indeed resulted in significant back injuries that prevented ibn Firnas from continuing his flight experiments. Accounts of his attempt, however, circulated throughout Europe centuries after his death, and his legendary experiment figured in later attempts at single-pilot glider flight conducted most prominently by Roger Bacon and Leonardo da Vinci.

IMPACT

Ibn Firnas is remembered as a Renaissance figure (more than five hundred years before the European Renaissance) for his contributions to several disciplines in the natural sciences. A scientist, ibn Firnas defined the pragmatic solution-driven side of the scientific enterprise, always seeing innovations and the application of insight as a way to address specific problems. Thus, he is a precursor to the industrial and technological revolutions that were at his time still several centuries off.

Although his work in geology and astronomy was groundbreaking (particularly his pioneering work in crystal cutting and artificial crystal manufacturing), he comes to contemporary audiences largely by virtue of his daring visionary certainty that controlled flight was scientifically feasible. As an aviation pioneer, ibn Firnas left a legacy that elevated the status of the individual scientist to that of a heroic figure flying—in this case, literally—in the face of conventional wisdom: Ibn Firnas executed his own designed flight against the popular assumption that flight was left for the gods, an experimental flight executed not as a stunt but rather as a laboratory test of a theory in the face of the threat of bodily harm, even death.

To a much larger degree, however, ibn Firnas has become a foundational figure in the assertion of the primacy and achievement of Islamic culture, how Islamic ingenuity and scientific acumen for seven hundred years in Moorish Spain predated Western advances in some cases by centuries, although the complete record of that achievement was deliberately destroyed. Thus, ibn Firnas, given the range of his work, the audacity of his experimentation, and the breadth of his vision, has been embraced by contemporary Islamic culture with the same enthusiasm and admiration that the Orville and Wilbur Wright or Leonardo da Vinci are held in Western culture. Indeed, he is one of the seminal figures used to demonstrate to contemporary audiences the importance of the caliphate era in Moorish Spain, as ibn Firnas's rise to prominence coincided with what has come to be regarded as continental Europe's greatest sustained era of culture—intellectual, artistic, scientific, and philosophical—after the collapse of Rome.

—*Joseph Dewey*

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See also: Roger Bacon; George Cayley; Galileo; Louis-Sébastien Lenormand; Leonardo da Vinci; Joseph-Michel and Jacques-Étienne Montgolfier; Faust Vrančić; Wilbur and Orville Wright.

EDWARD GOODRICH ACHESON

American chemist

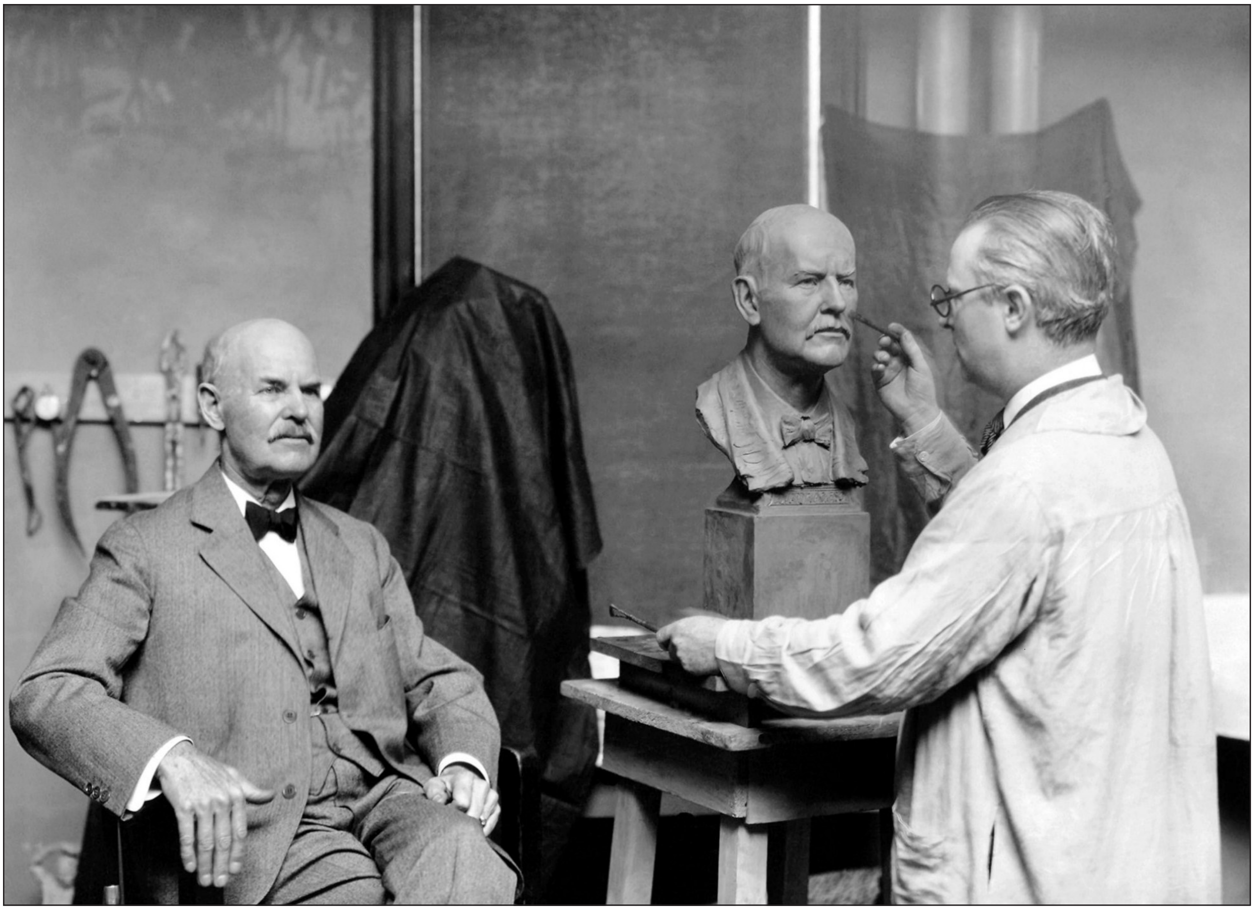
Acheson's research led to the discovery of carborundum, an important abrasive second only to the diamond in hardness. He also produced graphite in a very pure form, which resulted from heating carborundum to a high temperature.

Born: May 9, 1856; Washington, Pennsylvania
Died: July 6, 1931; New York, New York
Primary field: Chemistry
Primary inventions: Carborundum; graphite-making process

Early Life

Born and raised in southwestern Pennsylvania, Edward Goodrich Acheson was educated at home by his parents, William and Sarah Acheson. He briefly attended Bellefonte Academy in Bellefonte, Pennsylvania, but was largely self-taught. He excelled in mathematics and mechanics. In 1872, at the age of sixteen, he filed a patent caveat for a force auger for use in coal mining.

In the following year, his father died, and Acheson was forced to work full-time in order to provide for his mother and sisters. He worked at various railroad jobs



Edward Goodrich Acheson, who discovered carborundum (silicon carbide), an extremely hard synthetic abrasive useful for industrial applications, poses for a bust in this undated photo. (AP/Wide World Photos)

and surveyed tank capacities in the oil fields. Briefly, he even attempted mining iron ore in a partnership with his brother, William. Acheson continued to study and invent in the evenings, focusing mainly on electricity, and hoped to work for an employer manufacturing electrical equipment. He applied to Edward Weston, a manufacturer of electroplating dynamos, but was turned down. Working on his own, Acheson created an electric pile. He took the battery to Thomas Alva Edison, who saw promise in the young inventor and hired him on September 12, 1880, to work in his workshop in Menlo Park, New Jersey.

LIFE'S WORK

Working under John Kruesi, Acheson experimented with developing a conducting carbon for Edison's electric light bulb, and he was successful enough to be credited with contributing to Edison's invention. More important, Edison appreciated Acheson's inventiveness. About a year and a half after he started working for Edison, Acheson was sent to Europe as assistant chief engineer. During the next two and a half years, he installed electric generating plants and lamp factories in England, France, Italy, Belgium, and the Netherlands. Among the most notable public buildings in which he established successful electric lighting systems were the Hôtel de Ville in Antwerp, the Musée du Nord in Brussels, the Restaurant Krasnapolsky in Amsterdam, and the La Scala Theater in Milan.

In 1884, Acheson returned to the United States, stopped working for Edison, and became a competitor as the superintendent of a plant manufacturing electric lamps. He married Margaret Maher in the same year and started a family that eventually included four daughters and five sons.

Acheson's dream was to create artificial diamonds.

His experiments after 1884 were directed to that end, but the road to that goal was long and arduous. Along the way, he invented a number of other highly useful materials. He earned the first of his seventy patents in 1886 with his invention of a "conductor of electricity," which he sold to George Westinghouse. Subsequently, the Standard Underground Cable Company purchased the patent and developed it further in its electrical transmission business. Acheson continued his research into high-temperature electric furnaces, a necessary first step in the development of the abrasives for which he would become famous.

In 1891, he obtained the use of a powerful electric generating power plant in Port Huron, New York (at Edison's suggestion), where he worked to impregnate clay with carbon in an attempt to create artificial diamonds. The resulting mass contained some small, shiny specks, which turned out to be silicon carbide, which he called "carborundum"—a name based on his mistaken belief that he had combined carbon with alumina. On February 28, 1893, he patented a method for making silicon carbide. The silicon carbide he created was the hardest synthetic abrasive in the world, rivaling the diamond in hardness.

In 1894, Acheson started the Carborundum Company in Monongahela City, Pennsylvania, to produce a variety of grinding and abrasive tools and materials, including grinding wheels, knife sharpeners, whetstones, and abrasive powders. This plant quickly became too small to keep up with demand, so Acheson established a second, larger plant at Niagara Falls, New York, in 1895, when his factory became the second company to establish a long-term business arrangement with the Niagara Falls Power Company.

By 1896, Acheson had discovered that, if he heated carborundum to about 7,500° Fahrenheit (about 4,150° Celsius), the silicon would vaporize, leaving behind a very pure graphite (carbon). Later that year, he patented this process. Graphite was especially valuable at this time as an abrasive and, counterintuitively, as a lubricant. It was also used in the loop filaments in the incandescent lamps of the era.

In 1899, the Acheson Graphite Company was formed to manufacture the graphite, which was increasingly in demand for various uses. Acheson now was able to produce the graphite from calcine carbon and anthracite coal. This company merged with the National Carbon Company in 1928 and ultimately became Union Carbide.

Acheson also expanded the use of graphite as a lubricant. He suspended it in a variety of liquids such as oil and water, producing the commercial colloidal graphite products Oildag and Aquadag, which were manufactured by the Acheson Colloids Company (later Acheson Industries). Altogether, Acheson successfully established at least five major industrial corporations, including the International Acheson Graphite Company (1908) and the British Acheson Oildag Company (1911), in addition to those mentioned above.

Acheson was not a particularly effective manager. Many of his companies had to be reorganized or removed from his direct control by concerned investors, but this fact should not obscure the significance of his inventions. His accomplishments have been recognized by a number of honorary degrees and awards from a wide

CARBORUNDUM AND GRAPHITE

Edward Goodrich Acheson developed very high-temperature electric furnaces that he used in novel ways to create some very important industrial products, some of which were created by accident. In the 1880's, he was trying to create artificial diamonds by heating various carbon compounds to a very high temperature. In 1891, he discovered carborundum, mistakenly believing that he had created an alumina compound when in fact he had created silicon carbide. Silicon carbide occurs in nature as the extremely rare mineral moissanite (named for its discoverer, French chemist Henri Moissan). Silicon carbide is an extremely useful abrasive, and it is synthesized from inexpensive raw materials. Considered one of the most important inventions of the industrial age, the material is used in a variety of applications—from sandpapers to cutting tools to semiconductors—and has been used as a diamond simulant.

While heating carborundum to a temperature of 7,500° Fahrenheit (about 4,150° Celsius), Acheson created a nearly pure graphite, and the new process was duly patented. Graphite was an important material used in the carbon filaments in Thomas Alva Edison's incandescent light bulbs. This was Acheson's first claim to fame. Perhaps more important to world history was the fact that Acheson's graphite was also used as a neutron moderator in the nuclear fission experiments of Enrico Fermi, who created the world's first nuclear reactor in a secret laboratory at the University of Chicago in 1942. This was significant because the German nuclear program during World War II lacked access to high-quality graphite and instead used scarce heavy water as a moderator, delaying its development of nuclear fission and preventing the Germans from building an atomic bomb.

variety of chemical, industrial, technical, and manufacturing organizations. In 1997, he was inducted into the National Inventors Hall of Fame.

IMPACT

In 1926, the U.S. Patent Office rated Acheson's discovery of carborundum (silicon carbide) as one of the twenty-two most important patented inventions responsible for creating the industrial age. Carborundum has played a critical role in the manufacture of precision-ground interchangeable metal components. Without carborundum, mass production of these specialized parts would be impossible. Carborundum has also been used in the production of almost pure graphite.

Graphite has its own role to play as an abrasive and as a lubricant, but it has even played a significant role in the production of nuclear energy. Graphite is a valuable neutron moderator in nuclear reactors. Without a significant supply of graphite, the U.S.-British development of the atomic bomb in World War II might not have been possible, since the only known alternative to graphite was "heavy water" (an isotopic form of water), of which Germany possessed most of the world's supply.

Acheson was an active inventor, establishing five major industrial corporations that used electrothermal techniques. He patented seventy different abrasives, oxide reductions, refractories, and graphite products.

—*Richard L. Wilson*

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See also: Walther Bothe; Enrico Fermi; H. Tracy Hall; Elijah McCoy; Nikola Tesla; Alessandro Volta.

GEORGE BIDDELL AIRY

British astronomer

Airy's inventive genius was in the fields of optics, engineering, and computational methods. His most practical inventions included the optical method for correcting astigmatism in eyes and a method for compensating a compass on a metal ship.

Born: July 27, 1801; Alnwick, Northumberland, England
Died: January 2, 1892; Greenwich, England
Primary fields: Mechanical engineering; optics; physics
Primary inventions: Astigmatism-correcting lenses; compass compensation

EARLY LIFE

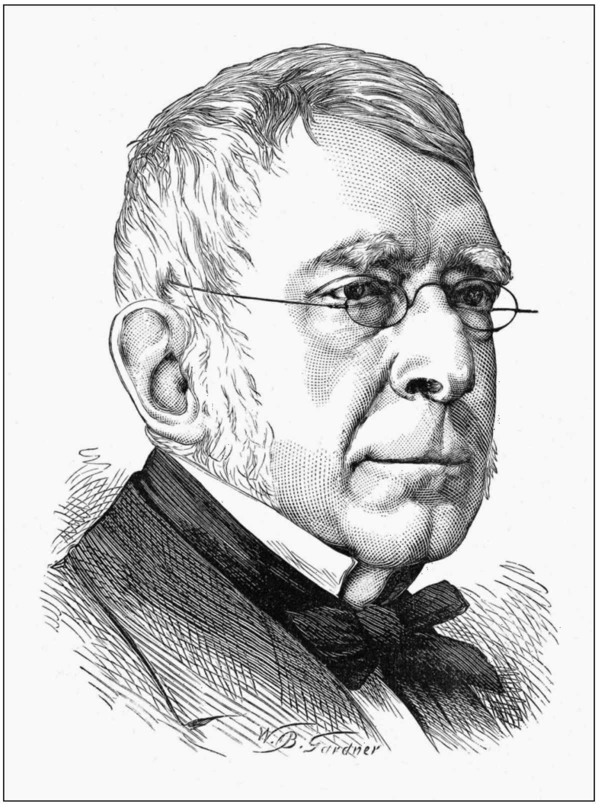
George Biddell Airy (EH-ree) was born into a family that could trace its origins back to the fourteenth century. His father, William, was a tax collector in Northumberland and his mother, Ann, was the daughter of a farmer in Suffolk. George was their first of four children. In 1802, William was appointed to Hereford, where his children attended elementary schools. George was a diffident child who was more popular with his teachers than with his peers, and he excelled at mathematics and writing. His father's transfer to Essex in 1810 made it possible for George to enter a more complete school at Sir Isaac's Walk, where he studied geography, orthography, and mathematics. George also read extensively among his father's books and committed to memory a prodigious amount of poetry. It was in reading his father's encyclopedia that he developed a fascination with technical matters, especially engineering, shipbuilding, astronomy, optics, and navigation.

Attending more advanced schools, Airy soon attained proficiency in Greek and Latin, as well as mathematics, chemistry, and physics. His uncle, George Biddell, recognized his potential and persuaded his father to send him to college. Airy was subsequently examined by scholars from Trinity College, Cambridge, and his performance easily paved the way to admission.

He entered Cambridge University in 1819 and graduated in 1823 after an exceptional academic career that included high distinction in his studies and several important early investigations and inventions, including designs for achromatic telescopes and experiments for the design of a mechanical computer. Upon graduation, he was appointed a fellow of Trinity College, a position of considerable responsibility involving teaching and research. While a fellow, he developed new mathematical methods for treating the motions of celestial bodies.

LIFE'S WORK

Airy's many publications and the quality of his lectures led to his promotion to the prestigious position of Lucasion Professor of Mathematics at the age of twenty-five. Continuing his rapid rise in academia, he was named Plumian Professor of Astronomy and Natural Philosophy and director of the Cambridge observatory in 1828, only two years later. The work that Airy did in expanding the observatory and its productivity brought him much favorable recognition. His fundamental investigations of planetary orbits, especially the rhythmic relationships of Earth's and Venus's orbits (called planetary inequalities), and his work in optical theory brought such honors as the Copley Medal and the Royal Astronomical Society's Gold Medal. As an inventor and innovator, his



George Biddell Airy. (The Granger Collection, New York)

ASTIGMATISM-CORRECTING LENSES

Glasses to correct for eyes that focused incorrectly were well known in George Biddell Airy's time. Myopia, the condition in which the eye focuses short of the retina, leading to poor focus for distant objects, could be corrected by wearing concave lenses; hyperopia (far-sightedness), the opposite condition, was corrected by convex lenses. However, astigmatism, the condition in which the shape of the cornea is not symmetrical, causes the focus to be confused and irregular and cannot be corrected with a simple lens.

Airy's eyes were decidedly astigmatic, the left eye being especially so. In the 1820's, while he was exploring various properties of light, it occurred to him that he might be able to invent a way of correcting for astigmatism. In August, 1824, he carried out several experiments on his eyes that allowed him to deduce the shape of the cornea of each eye. With his knowledge of the behavior of light rays, he was then able to design a specially shaped lens (called a cylindrical lens) that would compensate for the nonsymmetrical shape of the cornea. When he ordered these lenses to be made, they were found to be effective, and he wore them from then on. He was said to carry several pairs of glasses in his pockets in case of emergency.

Unlike some of Airy's inventions, the discovery of astigmatism-correcting lenses was not one that he discussed much in his autobiography, which otherwise gives extensive and self-satisfied details about his many accomplishments. There are only two sentences about this discovery. He says, "On August 25th I made experiments on my left eye, with good measures, and on Aug. 26 ordered a cylindrical lens of Peters, a silversmith in the town, which I believe was never made. Subsequently, while at Playford, I ordered cylindrical lenses of an artist named Fuller, living at Ipswich, and these were completed in November, 1824."

Although he gave it little notice in his writings, the invention of astigmatism-correcting lenses was without doubt one of Airy's most important inventions. Basically the same design has been used for eyeglasses for millions of people and for nearly two hundred years.

work at Cambridge involved the design and building of an impressive observatory, one that was far more effective than the small facility he found when he took over as director.

In 1835, Airy began a new life as astronomer royal and director of the Royal Greenwich Observatory. Reluctantly giving up his Cambridge professorship, Airy moved his family to London and took up residence in the observatory. During Airy's remarkably long tenure at Greenwich, he accomplished a great deal, much of it related to astronomy, but also much concerned with the observatory's mandate of improving the means of accurate celestial navigation at sea. As was his habit, Airy approached all tasks with his penchant for precision and orderliness, as well as for mathematical representation of practical problems whenever it was possible. He was basically a theoretician, but he became an inventor or designer whenever it became necessary to achieve a particular goal.

An indication of Airy's range of interests and his inventive nature occurred in 1838, when he was asked to help solve the problem of the failure of magnetic compasses installed on iron ships, which were coming into use to replace wooden vessels. He investigated the problem theoretically and then experimented with a design of compensating magnets placed on the ship in appropriate places. The method was tested on the iron ship *Rainbow*, with Airy working on board the ship as it maneuvered in the Thames River near Deptford. The result was a perfect correction, allowing a subsequent voyage across the English Channel to Antwerp, with the compass performing excellently.

One of the major projects at Greenwich after Airy became the director was the design of a new kind of celestial position-measuring telescope, called the altazimuth telescope, which he designed in 1844. This new instrument permitted measurement of the position of the Moon precisely at any sky position. The determination of the Moon's position was needed for navigation, which was of great commercial and military importance to Great Britain. In the following year, he invented another type of telescope, called the reflex zenith tube, with which precise star positions could be determined at nearly any position in the sky.

Among the various nonastronomical projects that occupied Airy's inventive mind was a measurement of Earth's mean density, achieved in 1845 by measuring the pull of gravity at the surface and at the bottom of a mine using pendulums. Although the first experiments failed because of various disasters (including fires and floods), success was eventually achieved.

The year 1845 was also notable for what Airy did not do. The young Cambridge mathematician John Couch Adams had calculated a position for a hypothetical new planet beyond Uranus, having analyzed perturbations on the orbit of Uranus. Although various historians differ on the details of what happened next, it is probable that

Airy's curt dismissal of Adams's work when it was brought to him resulted in discouragement and inactivity. In the meantime, the French astronomer Urbain Le Verrier made similar calculations, transmitted them to Johann Galle in Germany, who immediately pointed his telescope in the indicated direction and discovered the new planet, eventually named Neptune. Airy's role in losing the distinction for Adams and for England resulted in something of a scandal. His autobiography states, "I was abused most savagely both by English and French."

Neptune was not the only mistake that Airy has become known for. In the early 1870's, he was asked by Thomas Bouch to evaluate the pressures that would be encountered by the Tay Bridge, a 2.25-mile-long railroad bridge that spanned the Firth of Tay near Dundee in Scotland. Airy used his new mathematical treatment of physical mechanics and concluded that the design should be able to withstand ten pounds per square inch. Bouch used that as a guide in the design, and the bridge was completed on September 26, 1877. During a violent winter storm on December 28, 1879, the bridge collapsed, taking a train and over seventy lives with it. Airy's contribution was only a small part of the reasons for the disaster, but his involvement nevertheless tended to tarnish his reputation, in spite of the many very positive achievements of his long life.

Impact

Few scientists have wielded as much power and influence for such a long period of time as Airy, who was astronomer royal of England for forty-six years. During his tenure, the Royal Greenwich Observatory became a major center for astronomical activity, especially with regard to stellar and planetary positions and issues of time. The world's prime meridian, from where all longitudes are reckoned, was established under Airy's directorship of the Royal Greenwich Observatory, and its exact position was established by the location of the Airy Transit Circle. The world's time, known as Greenwich mean time, was similarly established by that instrument, designed by Airy.

Airy was a brilliant mathematician, but he also had interests in other scientific fields, especially those in which his mathematical talents could be useful. His was an inventive mind, and he often turned his attention to practical matters, inventing new instruments and techniques and even doing such things as embarking on ships to test his ideas and his inventions. His colleagues would probably have said that his greatest impact was his insistence on the orderly and scientifically based approach to the solution of problems. He kept careful and complete notes about everything he did (which is why he could write an exhaustive autobiography), and his inventions and new designs were thoroughly documented through the stepwise approach he took to solving the problems that they were intended to solve.

—*Paul W. Hodge*

Further Reading

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See also: Hermann von Helmholtz; Elmer Ambrose Sperry; Rangaswamy Srinivasan.

GEORGE EDWARD ALCORN

American physicist

Alcorn designed innovative semiconductors and X-ray detection devices that were incorporated in numerous scientific, technological, and industrial applications. He also advanced aerospace, physics, and engineering technology through his roles as educator and administrator.

Born: March 22, 1940; possibly California
Also known as: George Edward Alcorn, Jr. (full name)
Primary fields: Aeronautics and aerospace technology; electronics and electrical engineering; physics
Primary inventions: Advanced semiconductors; imaging X-ray spectrometer

EARLY LIFE

George Edward Alcorn, Jr., was born on March 22, 1940, to George and Arletta Dixon Alcorn, both Kentucky natives. His parents aspired for him and his younger brother, Charles, to be well educated. Their father's technical abilities as an automobile mechanic may have inspired their interest in technology and science and their inventive curiosity. Both sons became physicists.

Alcorn's high school academic and sports achievements resulted in several honors, including the California Savings and Loan Outstanding Student Award and being selected a West Coast Fund fellow. Alcorn received a full college scholarship, funding four years of studies, and majored in physics when he enrolled at Occidental College, in Eagle Rock, California, in 1958. That college's student directory identified Alcorn's hometown as Los Angeles. In addition to excelling scholastically, Alcorn played football and baseball in college, lettering eight times in those sports.

In spring, 1962, Alcorn received a bachelor of science degree from Occidental, graduating with honors. Selected for a summer fellowship that year and the next, he conducted a computerized assessment of trajectory data associated with missile launches and their orbiting performance for North American Rockwell's Space Division. His work involved Saturn IV, Nova, and Titan 1 and 2 missiles. During the 1960's, Alcorn was among the few African American scientists and engineers affiliated with the National Aeronautics and Space Administration (NASA). Receiving a graduate fellowship, Alcorn continued studies at Howard University in Washington, D.C., specializing in nuclear physics to earn a master of science degree in 1963.

Alcorn pursued doctoral work at Howard in the fields of molecular and atomic physics, researching how negative ions form. He received a grant from NASA to fund his investigations and wrote his dissertation, "An Electron Impact Study of the Methylamine, Monoethylamine, Dimethylamine, and Trimethylamine." Alcorn graduated with a Ph.D. in 1967. During his studies, he qualified for Sigma Pi Sigma, the national physics honor society, and Sigma Xi, a science honor society. Alcorn married Marie Leatrice Davillier in Fallon, Nevada, on December 29, 1969, and their son was born in 1979.

LIFE'S WORK

For several years after receiving his doctorate, Alcorn held physics and engineering positions involving research, invention, and development in private industry, including Philco-Ford, Perkin-Elmer, and International Business Machines (IBM). He also joined the Electrochemical Society and the Institute of Electrical and Electronics Engineers (IEEE). In 1973, Howard University appointed Alcorn as IBM Visiting Professor for electrical engineering. He continued that professional affiliation throughout his career, eventually being promoted to adjunct full professor.

As an IBM inventor, Alcorn focused on semiconductor technology and secured U.S. and European patents that were assigned to IBM. In September, 1975, Alcorn and colleague James Downer Feeley filed for a U.S. patent for a plasma-etching method involving quartz surfaces: "Process for Controlling the Wall Inclination of a Plasma Etched Via Hole" (number 3,986,912; issued 1976). In December, 1977, Alcorn's "Process for Forming a Ledge-Free Aluminum-Copper-Silicon Conductor Structure," developed with Feeley and Julian Turner Lyman to eliminate electrical shorts present in other semiconductors, was approved as U.S. Patent number 4,062,720. Alcorn published abstracts describing his inventions in the *IBM Technical Disclosure Bulletin*.

In 1978, Alcorn resigned from IBM and accepted a position at NASA's Goddard Space Flight Center (GSFC), in Greenbelt, Maryland. Before he left IBM, he contributed to several U.S. patents, including a "Method for Forming Dense Dry Etched Multi-level Metallurgy with Non-overlapped Vias" (number 4,172,004; issued 1979) for etching circuit boards, and the "Hardened Photoresist

Master Image Mask Process" (number 4,201,800; issued 1980) for semiconductors.

At GSFC, Alcorn developed technology for space missions and to evaluate Earth's atmosphere. Some of his work, specifically defense-related projects, was classified. Alcorn designed his most notable invention, the imaging X-ray spectrometer, during his early years with NASA. He discussed this research at the 1982 International Electron Devices Meeting and published a report in that conference's proceedings. The 1984 patent for this spectrometer, which was created to image and analyze electromagnetic radiation X-ray sources more accurately than existing detectors, was assigned to NASA for use in such aerospace technology as telescopes. By June, 1985, Alcorn had filed a patent for a method of fabricating an improved spectrometer.

Alcorn encouraged minorities and women interested in engineering and science to achieve their goals in those fields. He assisted Dr. Freeman Hrabowski III, president of the University of Maryland, Baltimore County, in developing Meyerhoff Foundation programs, started in 1988, which helped African Americans earn doctoral degrees in mathematics, science, and engineering. Alcorn advised Meyerhoff scholarship recipients. He also created the Saturday Academy to provide inner-city children science and mathematics classes that were unavailable to them in their schools. Alcorn recruited minority engineers and scientists to work for NASA, which in 1984 presented him a medal recognizing his efforts to secure minority personnel and help minority-owned companies to develop effective research projects compatible with their technological needs and aspirations.

By 1990, Alcorn was GSFC's advanced programs manager, overseeing technology projects at that center. As deputy project manager of Space Station Advanced Development, his responsibilities included directing work to provide both immediate and long-term technology needs for the Space Station Freedom (now the International Space Station). In 1992, Alcorn became director of GSFC's Office of Commercial Programs. He promoted technology transfer, especially appropriation of aerospace devices and procedures created at GSFC laboratories by employees and contractors

THE IMAGING X-RAY SPECTROMETER

George Edward Alcorn applied his physics skills to develop instrumentation to analyze electromagnetic radiation X-ray sources for aerospace applications. With three colleagues, Alcorn initiated invention of an imaging X-ray spectrometer to aid researchers in acquiring data on the composition of distant planets and stars. His device functioned more consistently and accurately than existing imaging X-ray equipment, particularly electromagnetic radiation detectors. U.S. Patent number 4,472,728, "Imaging X-ray Spectrometer" (1984), cites information and prior patents that influenced his invention, including optical and electronics technical articles, a 1970 semiconductor radiation measurement device, a 1975 radiation image converter, a 1979 photosensitive matrix, and a 1980 semiconductor radiation detector.

Alcorn stated that the purpose of his spectrometer was for imaging X-ray sources, and he stressed that the device could be used for space research using X-ray telescopes. He described his spectrometer as consisting of a silicon semiconductor wafer containing an aluminum matrix inserted by thermomigration, a technique using heat to dope a semiconductor. X-ray detector cells, also called pixels, composed of silicon form a rectangular array. Aluminum electrodes in the cells deplete some silicon and electrical charges in the array, resulting in the X-ray energy present to start a photoelectric reaction with the remaining silicon and to create electrons that scientists secure for imaging purposes.

Alcorn emphasized that his invention could provide spatial and energy resolution of X-ray images more precisely than was possible with previous detectors, which often provided one type of resolution but not the other. He blamed insufficient silicon thickness, which he suggested should be approximately fifty mils, for limiting X-ray reactions, especially with high-energy X rays. Alcorn stated that his spectrometer could handle high-energy X-ray sources, performing capably in a wide band of energy measuring from one to 30 kiloelectronvolts. Inventors referred to Alcorn's spectrometer in patents for other spectrometers, detectors, and X-ray and imaging instruments from the 1980's into the early twenty-first century. Alcorn's imaging X-ray spectrometer was valuable for acquiring information about stellar and planetary phenomena inaccessible to space probes and manned spacecraft.

Recognizing structural and performance deficiencies in his spectrometer, such as current leakage, Alcorn utilized a laser-drilling technique he developed to construct an improved imaging instrument, which he described in a 1986 patent, "Method of Fabricating an Imaging X-ray Spectrometer" (number 4,618,380). He inserted phosphorous or other dopant materials, used to alter electrical charges, through laser-drilled holes in silicon semiconductors before thermomigration of aluminum electrodes in each cell occurred.

for industrial, business, educational, and governmental needs.

On a shuttle mission in September, 1994, Alcorn oversaw a Robot Operated Material Processing System (ROMPS) experiment, which evaluated possibilities for commercial manufacturing in microgravity. *Government Executive* magazine presented Alcorn a 1999 Government Technology Leadership Award to recognize his work establishing commercial applications for GSFC's Airborne Lidar Topographical Mapping System (ALTMS), for which he served as project manager. Alcorn stressed the benefits of this laser and digital technology with three-dimensional capabilities to map elevations effectively. In 2001, Donna M. Christian-Christensen, Democratic congresswoman from Vermont, commended Alcorn for helping businesses in the U.S. Virgin Islands through application of space technology. He served as GSFC Standards Review Board chairman in 2003.

In 2005, Alcorn was promoted to the position of assistant director for GSFC's Applied Engineering and Technology Directorate. In addition to NASA work, he continued teaching at Howard University and the University of the District of Columbia, which also designated him an adjunct full professor. Alcorn taught both undergraduate- and graduate-level physics and electrical engineering courses, including microelectronics and engineering mathematics, and discussed his insights regarding designing innovative semiconductors and other electronics devices. He received several campus awards recognizing this work.

IMPACT

Alcorn contributed to aerospace technology advancements as a physicist, teacher, and administrator. In the mid-twentieth century, scientists and engineers established basic semiconductor technology. Alcorn's experience in the 1960's working on molecular investigations and electronic procedures prepared him to envision and create innovative semiconductor devices and techniques that provided scientific and commercial benefits. Many of Alcorn's peers considered his development of plasma semiconductors as pioneering. Alcorn was one of the first scientists to use computer modeling to compare plasma etching with other etching procedures. His knowledge of particle physics, including competence with sputtering techniques and plasma, allowed him to improve on existing semiconductor designs. Since the late twentieth century, many semiconductor manufacturers produced Alcorn's designs and utilized processes, such as plasma-etching techniques, that he innovated.

In addition to offering practical applications, Alcorn's inventions, particularly the imaging X-ray spectrometer (for which he is best known) to analyze space materials, have advanced research possibilities. Scientists praised Alcorn for utilizing aluminum thermomigration, which they considered a novel approach, in that invention.

Alcorn received professional recognition for his inventions, including being named Inventor of the Year by NASA and the GSFC in 1984. In 1994, Howard University honored Alcorn in its Heritage of Greatness awards ceremony for scientific and technological accomplishments. He has also received financial awards recognizing his inventions. Through his example as teacher and inventor, Alcorn has inspired African Americans and other minorities to enter technological and scientific fields.

—*Elizabeth D. Schafer*

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Dimitrijev, Sima. *Principles of Semiconductor Devices*. New York: Oxford University Press, 2006. Textbook explains basic semiconductor features, including atomic structures and materials used to make semiconductors. Although Alcorn is not mentioned, terminology for devices and processes to which his patents refer are incorporated in this text. Figures and illustrations clarify technical descriptions.

Plotkin, Henry H., and George E. Alcorn. "New Markets for Advanced Space Systems." *Aerospace America* 34 (November, 1996): 32-36. Alcorn and a senior research scientist at the University of Maryland, Baltimore County, identify technologies initially created at GSFC for aerospace purposes that also have commercial, medical, and military applications, including data systems, data compression, imaging, fiber-optic transceivers, radiation-tolerant components, and error-detection and error-correction processes and devices.

Sluby, Patricia Carter. *The Inventive Spirit of African Americans: Patented Ingenuity*. Westport, Conn.: Praeger, 2004. Patent agent notes Alcorn's affiliation with NASA and the legalities regarding patent rights and financial compensation associated with inventors who are U.S. federal government employees. Seven of Alcorn's patents are listed in an appendix.

See also: John Bardeen; Calvin Fuller; Dorothy Crowfoot Hodgkin; Nick Holonyak, Jr.; Sumio Iijima; Shuji Nakamura; Robert Norton Noyce; Stanford Ovshinsky; Heinrich Rohrer; Wilhelm Conrad Röntgen; William Shockley; Sir Alan Walsh; An Wang.

ERNST ALEXANDERSON

Swedish American electrical engineer

Alexanderson developed a number of key innovations in broadcasting, in particular the Alexanderson alternator, the first reliable technology for voice radio broadcasting, and played a substantial role in the development of analog color television.

Born: January 25, 1878; Uppsala, Sweden
Died: May 14, 1975; Schenectady, New York
Also known as: Ernst Frederik Werner Alexanderson (full name)
Primary fields: Communications; electronics and electrical engineering
Primary invention: High-frequency alternator

EARLY LIFE

Ernst Frederik Werner Alexanderson grew up in a highly intellectual family. His father, Aron M. Alexanderson, was a professor of classical languages, first at the University of Uppsala and later at the University of Lund. His mother, Amelie (née von Heidenstam), belonged to the Swedish nobility and would have received a substantial education, although she appears to have held no professional responsibilities after her marriage, instead satisfying herself with the role of wife and mother. All the same, she instilled in her son a respect for education.

Alexanderson received a solid education, completing his secondary schooling at Lund High School and then attending the University of Lund for a year between 1896 and 1897. He then went to Stockholm to attend the Royal Institute of Technology, where he received a degree in mechanical and electrical engineering in 1900. Feeling that the relatively provincial institutes of higher learning in Sweden would limit his long-term career success, he decided to study abroad.

Alexanderson's next stop was Berlin, where he studied in the German Empire's Royal Technical Institute. One of his teachers there was Adolf K. H. Staby, who had developed a primitive sort of radio communication based on generating and detecting artificial bursts of static. It was more a proof-of-concept device than a working radio system, and when Italian inventor Guglielmo Marconi put himself forth as the inventor of radio, Staby made no protests.

By this point, Alexanderson had a good grasp of the potential of radio technology, but he was increasingly convinced that no European country would give him the opportunity to exercise his abilities to the fullest. Looking at the developments that were occurring in the United States at the time, he decided that the country would offer him the best opportunity for practical work.

LIFE'S WORK

Alexanderson arrived in New York in 1901 and soon made the acquaintance of Thomas Alva Edison, the folksy "elder statesman" of the electrical world. In 1904, Alexanderson passed General Electric's engineering examinations and was hired by the company. Thus, he was in a perfect position to make his reputation when radio pioneer Reginald Aubrey Fessenden was looking for someone to build an alternator that other engineers claimed was impossible. Alexanderson examined a prototype and made significant changes that permitted the device to reach the necessary speeds. However, he took no chances on its safety: The first time he started the alternator, he placed it in a sandbagged pit just in case it were to fly apart as others claimed it would.

After his success with the alternator, which subsequently bore his name in spite of Fessenden's rather vociferous complaints that he had originally conceived of the concept, Alexanderson developed an entire series of important radio inventions. He created the multiple-tuned antenna, which permitted a radio to broadcast or receive on several different frequencies. He also created a magnetic amplifier, then rendered it obsolete with an electronic modulator that used vacuum tubes to create the same effect more reliably and at even higher power levels.

During this time, Alexanderson also gained a reputation for eccentricity and for being something of an absentminded professor. During periods of frenetic activity on a project, he would forget to eat unless food was brought to him. He frequently greeted friends as though they were complete strangers if he met them on the street rather than in the laboratory or office, and he once gravely shook hands with his own daughter and addressed her as “miss.”

However, such oddities of behavior were tolerated, if with a bit of wry humor, for the simple reason that Alexanderson was so prolific and his inventions so useful. After World War I, he became chief engineer for the newly created Radio Corporation of America (RCA). As RCA’s executive director, David Sarnoff, moved the radio industry away from being a transmitter of wireless telegrams for individuals and companies to being a news and entertainment medium via voice radio broadcasting, Alexanderson concentrated increasingly on various devices that would help make the radio receiver into an appliance that would be usable by a person with no technical background.

His skills in radio technology development also had a personal benefit, when his son Vernor was kidnapped in 1923. A description of his son was transmitted over the air with a request that anyone with information about the crime contact the police. Although receivers were still relatively new at the time, a janitor heard the broadcast and recognized the boy as one he had seen in the upstate New York resort at which he worked. He passed the word to the police, who were able to capture the kidnappers and return the boy safely to his parents.

By 1924, Alexanderson was becoming increasingly interested in the developing technology of television and as a result quit his job at RCA in order to work full-time with General Electric. He concentrated almost entirely on mechanical methods of scanning. One of his earliest devices used individual wires to convey the information for each pixel of the image. Although this technique allowed him to score the coup of transmitting one of the first-ever television images, it was not a practical technology for broadcast use. He later began using various slotted disks and mirror drums to scan and reconstruct an image, although they were necessarily limited by the tolerances to which they could be machined and the fact that most of the light reflected off the object being televised would be lost.

THE ALEXANDERSON ALTERNATOR

One of the most difficult challenges faced by Reginald Aubrey Fessenden in realizing his dream of making radio waves carry the human voice was the problem of generating a continuous carrier wave. In 1901, neither the vacuum tube nor the transistor existed, so any device that would produce a carrier wave would have to be mechanical in nature. Fessenden, who recognized that radio waves were an electromagnetic phenomenon, conceptualized an alternator that would change phase far more frequently than the usual 60 cycles per second of American line voltage, perhaps as much as 100,000 cycles per second.

However, when this consummate theorist approached engineers to actually construct his alternator, they told him that it was impossible to build. Anything rotating as rapidly as he had described would tear itself to pieces the moment it was turned on. Frustrated, Fessenden fell back on a makeshift method of generating a carrier wave for his very first voice transmission. However, he did not cease his search for an engineer who could build his alternator and give him a real carrier wave.

Although Charles Proteus Steinmetz of General Electric, one of the era’s foremost experts in electrical engineering, tried to build the device, he was only able to attain a speed of 4,000 cycles per second before the armature started shaking apart. Fessenden turned to Ernst Alexanderson, who had already established his reputation for both eccentricity and technical genius.

Alexanderson had to apply all his technical ingenuity, along with the construction resources of General Electric, to construct the device. Instead of just speeding up a normal alternator, he altered the structure of it so that the rotor became a flat disc that turned inside a stationary armature. The outside edge of the rotor turned at an amazing 700 miles per hour, but it was so perfectly balanced that it wobbled less than three hundredths of an inch.

Alexanderson’s alternator would become the mainstay of voice radio transmission for more than a decade. However, it had several drawbacks, most importantly its huge size and difficulty of manufacture, which restricted the alternator to the largest of stations with the resources to acquire and operate one. Once Edwin H. Armstrong demonstrated that vacuum tubes could be used to generate and modulate a carrier wave, the Alexanderson alternator gave way to the new technology. Tubes would prove to have a surprising staying power, particularly for high-wattage stations, even after the transistor and the integrated circuit were introduced.

However, Alexanderson did provide some insights that were later used by Vladimir Zworykin in his work on the all-electronic television.

During World War II, Alexanderson worked on a number of projects for the U.S. military, including a direct-current generator that used a smaller current to control a much larger one. Although the generator was originally designed for use in steel mills, it later found application in the controls for antiaircraft guns. In 1948, Alexanderson retired from General Electric, although he continued to work as a consultant for the company and RCA. This arrangement allowed him to take only the projects that attracted his interest.

During the 1950's, Alexanderson made his last major contribution to broadcast technology. Peter Carl Goldmark of the Columbia Broadcasting System (CBS) had developed a hybrid mechanical-electronic system of color television and was touting it to the Federal Communications Commission (FCC) as a replacement for the National Television Standards Committee (NTSC) black-and-white television standard. The Goldmark system involved using a rotating disk with red, green, and blue lenses that would be passed over the electronic camera on the transmitter end, so that the image would be transmitted in sequential red, green, and blue frames that would be put together by a similar rotating disk over the picture tube. However, this system would have two major limitations. First, it would instantly render obsolete the existing NTSC televisions. Second, to attain a picture size much larger than a postage stamp would require a large disk. To create color televisions as big as sets already in existence would require disks as large as a house, and their outer edges would rotate at speeds of hundreds or even thousands of miles per hour, such that if they were to suffer mechanical failure, the fragments would become deadly shrapnel.

Sarnoff knew that the only workable solution was an all-electronic television. Alexanderson developed a system by which the camera would have three image tubes in parallel, one for each primary color, and the picture tube of the receiver would have three corresponding electron guns. In addition, Alexanderson's system separated the color information into a separate part of the signal for the brightness of each pixel, so that color signals could still be received on black-and-white sets. This compatible color scheme was quickly approved by the FCC and would remain the American color television standard until its replacement in the early part of the twenty-first century by digital television.

In his later years, Alexanderson was the recipient of many honors for his radio and television work. He also developed a strong fondness for sailing. He died at his home in Schenectady at the age of ninety-seven, having survived two wives.

IMPACT

Although most of Alexanderson's inventions have been superseded by more advanced technologies (the Alexanderson alternator with the triode vacuum tube and the NTSC compatible color system with digital television), his inventions enabled radio and television to become sufficiently commercially successful that continued innovation was profitable. On December 24, 1906, using Alexanderson's alternator, Fessenden broadcast the first transmission of voice over radio waves. Alexanderson also designed a color television receiver for RCA, establishing the color television standard that lasted for decades. Alexanderson earned more than three hundred patents during his lifetime.

—*Leigh Husband Kimmel*

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See also: Edwin H. Armstrong; Lee De Forest; Thomas Alva Edison; Philo T. Farnsworth; Reginald Aubrey Fessenden; Peter Carl Goldmark; Guglielmo Marconi; Vladimir Zworykin.

LUIS W. ÁLVAREZ

Spanish American physicist

Álvarez invented the microwave phased-array antenna and several radar systems that used it. He was coinventor of the exploding-bridgewire detonator for atomic bombs. He also developed the liquid-hydrogen bubble chamber, and with his son, an asteroid-impact extinction theory.

Born: June 13, 1911; San Francisco, California
Died: September 1, 1988; Berkeley, California
Also known as: Luis Walter Álvarez (full name)
Primary fields: Electronics and electrical engineering; military technology and weaponry; physics
Primary inventions: Phased-array antenna; exploding-bridgewire detonator; liquid-hydrogen bubble chamber

EARLY LIFE

Luis Walter Álvarez (AHL-vah-rehz) was born on June 13, 1911, in San Francisco, California. His mother was Harriet Smyth Álvarez, who grew up in China, where her Irish parents started a missionary school. His father was Walter C. Álvarez, a physician and medical researcher at the Universities of California and Minnesota (Mayo Foundation), who wrote a widely read syndicated medical column. His grandfather, Luis F. Álvarez, was born in Spain and educated in Cuba before medical studies at Stanford.

Luis Álvarez had two sisters, Gladys Álvarez Mead and Bernice Álvarez Brownson, and one brother, Robert Álvarez, all of whom lived in the San Francisco Bay Area. When Luis was eleven, he and his father built a crystal radio receiver, which could pick up the first music broadcast from San Francisco. Young Luis attended the Madison Elementary School for six years and the Polytechnic High School in San Francisco for two years. After his family moved to Minnesota in 1926, he graduated from Rochester High School in Rochester, Minnesota, where he attended for two years.

In 1928, Álvarez entered the University of Chicago, where he earned his bachelor of science degree in 1932, master's degree in 1934, and Ph.D. in 1936. While still an undergraduate, he published his first paper, "A Simplified Method for the Determination of the Wave Length of Light," using the grooves of a phonograph record as a reflection grating to form a spectrum. As a graduate student under Nobel Laureate Arthur H. Compton, he built a pair of Geiger counters, among the first in the United States, and used them to make the important discovery that most cosmic rays are positively charged. His Ph.D. thesis was published in 1936 as "The Diffraction Grating at Grazing Incidence." His first marriage was to Geraldine Smithwick in 1936, and a few years later his first two children were born, Walter and Jean.

LIFE'S WORK

Álvarez began his scientific career in 1936 as a research fellow at the University of California Radiation Laboratory, where he concentrated on nuclear physics and on the development of the cyclotron with its inventor, Ernest Orlando Lawrence, as his mentor. Using the 27-inch-diameter cyclotron, he studied neutron yields from deuteron (bound proton-neutron particle) reactions in 1938 and developed a method for producing beams of slow neutrons. With his student, Jake Wiens, he invented a mercury-vapor lamp by using neutron capture by the gold-197 isotope to transmute gold into mercury 198, which emitted a very pure form of green light that served as the accepted standard for many years. Soon after learning in early 1939 about the discovery of nuclear fission, he confirmed this by bombarding uranium with cyclotron-generated neutrons. During this period, he worked with Lawrence to design a new 60-inch-diameter cyclotron.

In November of 1940, as World War II spread across Europe, Álvarez was sent with other nuclear physicists to assist in the beginning of the Massachusetts Institute of Technology (MIT) Radiation Laboratory to develop radar (radio detecting and ranging) systems for military applications. Working with an airborne 3-centimeter microwave radar system for antisubmarine warfare, he invented the Vixen system, which "outfoxed" submarine listening sets by decreasing the strength of the radar signals during approach. In this way, U-boat crews would think they were undetected and remain on the surface long enough to be attacked.

This work with radar and his experience as a licensed pilot led Álvarez to invent the first ground-controlled approach (GCA) system for landing airplanes in conditions of low visibility. His idea required a very narrow fan-shaped beam so that a ground-based radar operator could guide a pilot in the blind landing of his airplane. Drawing on his experience with diffraction gratings, he invented the first phased-array antenna, consisting of a series of radiating elements from which the radiation is reinforced in one direction and suppressed in all other directions.

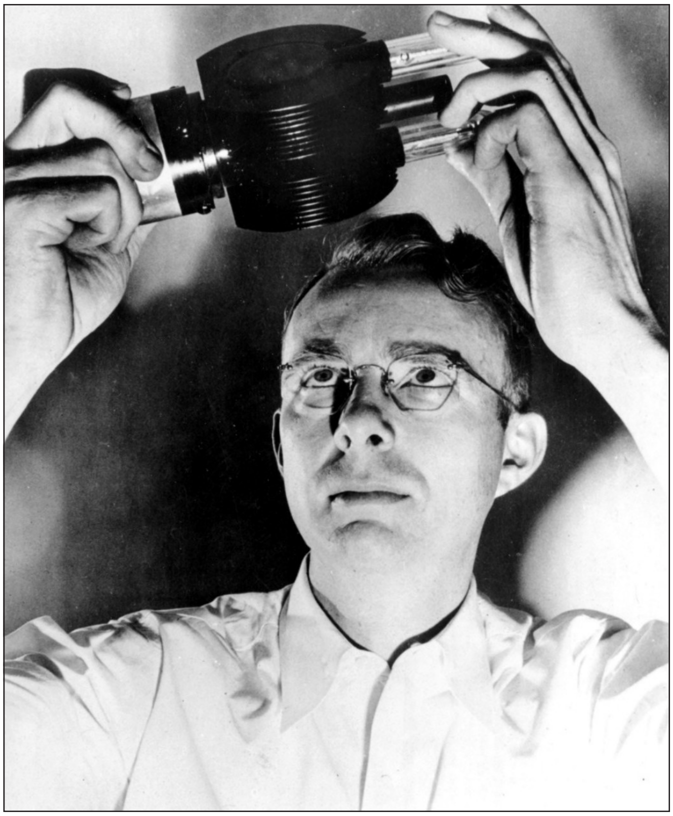
Later in 1941 as head of the Special Systems Division of the MIT Radiation Laboratory, Álvarez led the development of two more of his radar-system inventions using phased-array antennae. The microwave early warning (MEW) system could detect enemy aircraft in overcast skies early enough to defend against them. It was used to coordinate the D-day landing and to defend against German V-1 buzz bombs. The Eagle high-altitude bombing system could locate targets and aim bombs at night through overcast skies more accurately than visual bombsights during the day.

In the fall of 1943, Álvarez was asked to join the Manhattan Project to help develop the atomic bomb. For six months he worked with Nobel Laureate Enrico Fermi on continuing tests of the first nuclear reactor, which had been moved from the University of Chicago to the new Argonne National Laboratory in a Chicago suburb. Then, in the spring of 1944, he was invited to Los Alamos in New Mexico to assist with the implosion mechanism for triggering plutonium bombs. With his student Lawrence Johnston, Álvarez invented the exploding-bridgewire (EBW) detonator for spherical implosives in the Fat Man-type atomic bombs used in the first nuclear explosion at the Trinity Site near Alamogordo, New Mexico, and in the bomb dropped on Nagasaki, Japan. He flew as a scientific observer at both the Trinity and Hiroshima explosions.

After the war, Álvarez returned to particle-accelerator research at the University of California Radiation Laboratory and was named professor of physics. In 1947, he completed the design and construction of a 40-foot proton linear accelerator. He assisted in the development of one of the first proton synchrotrons, the 6-billion-electron-volt (6-GeV) Bevatron, a 36-meter-diameter cyclotron in which the magnetic and electric fields were increased synchronously with increasing proton energy and associated mass.

In 1954, Álvarez began developing the first liquid-hydrogen bubble chambers for detecting elementary particles from the trail of bubbles they produce in superheated liquid hydrogen. After demonstrating the technique with several smaller chambers, he led his group in the development of a 10-inch chamber in 1955 and a 72-inch chamber over the next four years for use in the Bevatron. During this time, he invented automatic tracking and recording methods and participated in the discovery of many new short-lived elementary particles. By the time he was awarded the Nobel Prize for this work in 1968, the 72-inch chamber was detecting 1.5 million events per year.

In the 1970's, inventions by Álvarez included a variable-focus thin lens used in the eye-care field, methods for stabilizing images in cameras and viewing devices, and a handheld color television system. In 1978, he was inducted into the National Inventors Hall of Fame. In the 1980's, he worked with his geologist son Walter Álvarez in inventing the asteroid-extinction hypothesis, which provided an explanation for the disappearance of the dinosaurs 65 million years ago. This was based on their discovery that a thin dark layer in the geological column at the Cretaceous-Tertiary boundary worldwide contained relatively large amounts of the rare element iridium. Since meteorites are rich in iridium, the scientists recognized that a large asteroid collision could have produced a global fallout of debris that would kill



Luis W. Álvarez examines a radio transmitter used in his ground-controlled approach (GCA) system for landing airplanes in conditions of low visibility. (AP/Wide World Photos)

THE PHASED-ARRAY ANTENNA

One of the lesser-known but most important inventions of Luis Álvarez was his microwave phased-array antenna. He needed a thin (3°) fan-shaped radar beam for the microwave early warning radar system, which would have required a rectangular reflector 8 × 75 feet when fed by a single radiating (dipole) element. He then realized that he could obtain better results from a series of many equally spaced radiating elements along a pipelike waveguide, which he found would require a length of only 24 feet for a 3° beam. Microwaves from the waveguide, radiating out from these elements, would overlap and reinforce each other in one direction and cancel in all other directions. This produced the desired fan-shaped beam perpendicular to the waveguide when the separation between the elements was one wavelength (or a phase difference of 360°).

When Álvarez used this new linear-array antenna concept in his Eagle bombing system, he realized that he could steer the beam by varying the width of the waveguide. This changed the wavelength of radiation in the waveguide and thus the phase of the radiating elements in such a way that radiation would be reinforced in differing directions. Later it was shown that rapid scanning of a phased-array antenna can also be achieved by varying the frequency of the generator or with electronic phase shifters between elements, which are often just slots along one side of the waveguide.

These phased-array techniques were developed after the war by Hughes Aircraft Company to produce a planar array with a pencil beam that could be rapidly scanned in any direction by changing the phase between elements in both dimensions. Since such antennae required no mechanical steering, they could be easily mounted in aircraft or built to nearly unlimited size for many military and civilian applications. They are used for missile guidance, as in the Patriot (phased array tracking radar to intercept of target) missile system, and for battle-control radar, such as the U.S. Navy Aegis combat system, which can simultaneously search and track more than one hundred targets. They are also used in very large ground-based radar antennae for over-the-horizon defense and in the MESSENGER spacecraft mission to Mercury for communicating back to Earth.

many species of life. On September 1, 1988, Álvarez died in Berkeley from cancer, perhaps due to years of radiation exposure, shortly before the discovery of a 200-kilometer-diameter crater near Chicxulub, Mexico, supporting the extinction theory.

IMPACT

Álvarez made many important contributions to both radar systems and high-energy physics, resulting in some forty patented inventions that helped win World War II and extended basic knowledge in physics. His invention of the phased-array antenna had important applications in World War II, and even more in the postwar period in both defensive and offensive radar systems. His antisubmarine Vixen system saved many lives and tons of allied shipping. His ground-controlled approach system for blind landing has saved many aircraft and their passengers in both military and civilian emergencies. The microwave early warning system and the Eagle bombing system played important roles in the safety and accuracy of allied missions. His work in the Manhattan Project helped to make the atomic bomb possible and to bring the war to an early end.

Both before and after World War II, Álvarez helped to make significant advances in high-energy physics. His work on the early development of cyclotrons, proton linear accelerators, and the synchrotron led to significant increases in the strength and energy of proton beams, helping to confirm nuclear fission and discover new elementary particles and their properties. His development of the liquid-hydrogen bubble chamber and invention of automatic tracking and measuring of high-energy particles led to many new discoveries and provided the experimental basis for the quark model of elementary particles. This and other work, ranging from optics to asteroid collisions, show an active and inventive mind.

—*Joseph L. Spradley*

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See also: Hans Geiger; Donald A. Glaser; Ernest Orlando Lawrence; J. Robert Oppenheimer; Sir Robert Alexander Watson-Watt.

MARC ANDREESSEN

American computer scientist and software engineer

While an undergraduate at the University of Illinois, Andreessen, along with Eric Bina, created Mosaic, the first Internet browser to allow graphics and text to be viewed at the same time. The browser's 1993 release led to the initial surge in the popularity of the World Wide Web. Andreessen followed the success of his first browser with his second, Netscape Navigator, which served as the general public's portal to the World Wide Web.

Born: July 9, 1971; Cedar Falls, Iowa
Primary field: Computer science
Primary inventions: Mosaic; Netscape Navigator

EARLY LIFE

Marc Andreessen grew up in New Lisbon, Wisconsin, a small, rural town with a population of 1,500. He lived ten miles outside of town and was raised by working parents. At the age of twelve, while he was recovering from surgery, Andreessen convinced his parents to purchase him a Radio Shack computer, and he quickly discovered a love for programming.

Andreessen attended a small high school, where he was a top scholar. He also politely challenged authority, questioning, among other issues, the relevancy of classroom practices. After graduation, he attended the University of Illinois at Urbana-Champaign, where he majored in computer science. He also landed a programming position with the National Center for Supercomputing Applications (NCSA), where he learned of Tim Berners-Lee's work with open standards for the World Wide Web.

Andreessen was originally hired to write software for three-dimensional scientific visualization. However, his enthusiasm for the early form of the Internet led him to begin working on writing the code for what he hoped would be an effective means of navigating the Internet. Andreessen and full-time University of Illinois employee Eric Bina collaborated on the creation of a Web browser (software that displays the files retrieved from the Internet) that would be both user-friendly and would allow graphics to be displayed as an integrated component of a Web page. (Earlier browsers could only show text and graphics files as separate pages.) The pair also wanted their browser to run on a wide range of computing platforms, from UNIX to Windows.

The result of their programming effort was a browser that they named NCSA Mosaic. Version 1.0 was released for UNIX's X Window System on April 22, 1993.

LIFE'S WORK

Andreessen never expected the Internet, nor Mosaic for that matter, to become wildly popular. His goal was to create a browser that would make the Internet easier to use through the graphical point-and-click interface. At first, it seemed that Andreessen's vision of the Internet as a small network community used by only a handful of scientists and researchers might hold true: In February, 1993, only twelve people were using the early versions of Mosaic. However, after the April release of version 1.0 and the late spring release of the PC and Macintosh versions, ten thousand users were using Mosaic. The one millionth Mosaic browser was downloaded and installed in early 1994, and the fuse had been lit for the Internet explosion.

Andreessen graduated from the University of Illinois in December of 1993 and headed to Palo Alto, California, to work at Enterprise Integration Technologies, where he connected with Jim Clark, the founder of Silicon Graphics. Clark and Andreessen decided to create a new startup company whose goal was to become the "Microsoft of the Internet" by creating a browser that was more robust than Mosaic. They named the new company Mosaic Communications Corporation, and Andreessen put together an engineering team that included many of his old friends from NCSA. Their business plan was to create a commercially viable browser that would allow them to build their fortunes around it.

However, because the original Mosaic was the property of the University of Illinois, which objected to Andreessen and Clark's use of the Mosaic brand name, the company was renamed Netscape Communications Corporation. In December, 1994, the first full 1.0 version of the Netscape Navigator browser was released. The browser was freeware—that is, it was free for individuals to download for noncommercial purposes. Commercial interests could purchase licensed copies of the browser.

As the general public began to make use of the Internet in the mid-1990's, Netscape Navigator became the browser of choice, especially for PC systems. This growth was promulgated by the ever-increasing library of hypertext markup language (HTML) tags that Netscape Navigator made available to Web page designers. These tags were commands that gave Web designers increased flexibility in their designs and offered them the opportunity to produce dynamic pages with improved visual impact and greater levels of interactivity. Designers quickly utilized the new tags to make their pages more exciting, adding to their pages buttons that read, "Optimized for Netscape Navigator." The buttons were usually linked to a Web site where users could download the latest version of the Navigator browser for free.

On August 9, 1995, Andreessen became one of the early dot-com millionaires, as Netscape's initial public offering marked the beginning of the dot-com boom in the American stock market. At the age of twenty-four, he had become worth $58 million in just one day. He had also become one of the first popular icons among the Internet glitterati, as his face became a familiar sight on computing, finance, and news magazines of the day.

By 1996, two-thirds of all browsers in use were Netscape products. That success drew the attention of software giant Microsoft, which decided to enter the fray with a browser of its own. Microsoft's Internet Explorer, which began as a reworked version of Mosaic, would eventually eclipse Navigator. Microsoft accomplished this primarily through the practice of bundling the Internet Explorer browser with every Windows operating system and by producing a browser that was the technological equal of Netscape's product. Netscape was purchased by America Online (AOL) in 1998. Andreessen briefly served as AOL's chief technology officer before leaving in September of 1999.

MOSAIC AND NAVIGATOR

A Web browser is a software program that displays Web pages on a user's computer and allows him or her to "surf" the World Wide Web. Marc Andreessen and Eric Bina brought together all the potential that Tim Berners-Lee's World Wide Web technology had to offer, making their browser accessible and the Web easy to navigate. Earlier browsers such as Cello, Erwise, and ViolaWWW failed to deliver on either the integration of features or ease of use.

As a browser, Mosaic allowed seasoned users to continue to have access to older Internet technologies such as gopher (an early search protocol), file transfer protocol (FTP), and Usenet (discussion groups). Mosaic broke new ground in a number of areas. The browser was the first to include an image tag, allowing images to be displayed as an embedded component on a page. This marked the Web's first step toward becoming a multimedia communication medium.

Mosaic was also designed in a manner that made it intuitive, even for new users. The move away from a command-line interface made the browser user-friendly and helped drive its popularity. Mosaic's popularity was also boosted by the fact that it was designed to run on almost all of the available platforms of the day, including UNIX and Windows. The fact that the browser was available for free for noncommercial use was also an enormous factor in its popularity.

After Mosaic was released, the Web began to grow exponentially. Andreessen took his programming skills to Silicon Valley and, with Jim Clark, developed the next generation of browser by 1994, Netscape Navigator. In 1995, Microsoft, after observing the success of Navigator, licensed the Mosaic source code and built Internet Explorer, which was designed to directly challenge Netscape's market supremacy. The battle for users waged by the two companies, both in the marketplace and in the courtroom, has become known as the "browser wars."

IMPACT

NCSA Mosaic and Netscape Navigator were essential components in moving the World Wide Web from a supercomputer-based service that was utilized by a handful of academics, scientists, and engineers to its role as the communication medium of choice for a growing segment of the world's population.

Mosaic's impact lies in its technological innovation and ease of use. The inclusion of the graphics tag, which allows images to appear as a component on a page, was groundbreaking. Mosaic also utilized graphical interfaces that used "clickable" buttons, allowing users to move easily through Web pages. Mosaic's visual style and graphical interface set the standard for browser technology and for many other Internet applications for the foreseeable future.

Andreessen and Bina also made the hyperlink a great deal more user-friendly. Hyperlinks are links (usually indicated by underlined text) in a document that allow users to quickly "jump" to a related document elsewhere on the Web. In earlier browsers, hyperlinks were indicated by reference numbers, similar to footnotes, that the user had to type into the navigation bar to retrieve the document. Mosaic streamlined the process, allowing a user to merely click on an underlined link to retrieve a document.

Perhaps the greatest impact of Mosaic came from the fact that Andreessen and Bina quickly developed versions for personal-computer users. Mosaic was not the first PC browser (that honor goes to Cello), but what set it apart was the fact that the browser was so simple to download and install that even novice users had little trouble getting the software up and running. Because of this ease of adoption, the easy-to-understand graphical interface, the browser's availability for PC platforms, and the fact that the browser was free for noncommercial use, Mosaic's popularity, and with it, the popularity of the World Wide Web, skyrocketed. Most scholars mark the 1993 release of Mosaic as the moment that the Internet and World Wide Web became available to the general public. It also marked the beginning of the Internet's boom in popularity.

—B. Keith Murphy

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See also: Tim Berners-Lee; Robert Cailliau; Vinton Gray Cerf; Philip Emeagwali; Bill Gates; Bob Kahn; Robert Metcalfe; Larry Page.

ARCHIMEDES

Greek physicist, mathematician, astronomer, and engineer

Ancient Greek mathematicians were primarily interested in elegant conjectural theorems and proofs. Archimedes of Syracuse, exceptionally, if not uniquely, pursued not only abstract mathematical problems but also how solutions to those problems could be applied to create mechanical realities, including defensive weapons.

Born: c. 287 B.C.E.; Syracuse, Sicily (now in Italy)
Died: 212 B.C.E.; Syracuse, Sicily (now in Italy)
Also known as: Archimedes of Syracuse
Primary fields: Astronomy; civil engineering; mathematics; military technology and weaponry; physics
Primary inventions: Archimedes' principle; Archimedes' screw; claw of Archimedes

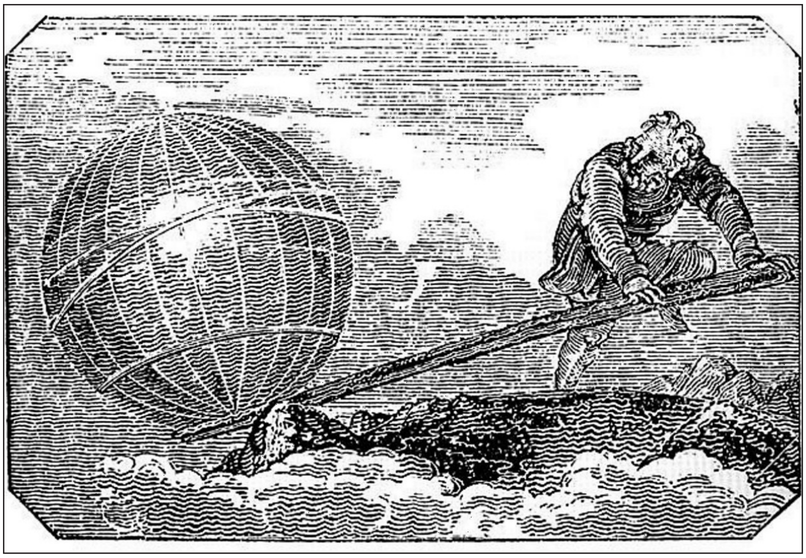
EARLY LIFE

Archimedes (ahr-kih-MEE-deez) was born c. 287 B.C.E. into a notable family in Syracuse, the wealthy and populous Greek city on the southeast coast of Sicily. His family had scientific credentials (Archimedes stated that his father, Phidias, was an astronomer, but all that is known of him is that he estimated the ratio of the diameters of the Sun and the Moon) and was manifestly wealthy: Archimedes received an elite education and corresponded with contemporary Greek intellectuals, including the mathematician and astronomer Konon of Samos (c. 245 B.C.E.) and the polymath Eratosthenes of Cyrene (c. 275-194 B.C.E.), sometime head of the Library of Alexandria (Egypt) to whom Archimedes dedicated two of his treatises. No information has survived as to whether Archimedes was married or had any children. He may have studied at Alexandria, but proof is lacking. He had no recorded employment and was said to be a kinsman of the long-term king of Syracuse, Hieron II (c. 305-215 B.C.E.).

LIFE'S WORK

The earliest firmly datable event in Archimedes' career came late in his life. Ancient literary authorities described Archimedes' applications of physical principles to mechanical inventions for the defense of his city. Archimedes reportedly constructed several (not entirely plausible) weapons to defend Syracuse, an ally of the Carthaginians in the Second Punic War, during a siege of the city by the Roman commander Marcus Claudius Marcellus in 213-211 B.C.E. Those reported weapons included gigantic metallic parabolic mirrors to focus the Sun's rays on the sails of Roman ships in Syracuse's harbor. More plausible are reports that he demonstrated the power of the compound pulley and block and tackle by constructing a track with cables to move very heavy ships into the water from dry land. That knowledge of applying the principle of leverage to the power of the compound pulley enabled the lifting of heavy objects. Thus, Archimedes constructed cranes to drop heavy weights (stones and lead) on attacking ships. Other cranes had an iron hook called "the claw" (attached to ropes), capable of lifting the prows of enemy ships out of the water and pulling up scaling ladders. These cranes were effective because Roman vessels attacking Syracuse had to sail close to the walls behind which the cranes operated.

Another ancient report also illustrates Archimedes' ability to find practical applications for physical principles. Archimedes stepped into a small bath, observed that his weight displaced water, then leapt from the bath shouting (so ancient sources say) "Eureka!" (actually,



Archimedes famously remarked about the lever, "Give me a place to stand and I shall move the Earth." (*Mechanics Magazine*, 1824)

Heureka, "I found [it]"). What Archimedes found was a solution to a problem posed by King Hieron II: What was the proportion of gold to silver in a wreath said to be of gold? Archimedes' bath suggested that the volume of an irregularly shaped object (a wreath or body) could be measured by the water displaced and that the specific gravity of different metals would displace different volumes of water—that is, a body immersed in water displaces a quantity of water equal to its own volume. By dividing the weight of the body immersed by the quantity of water displaced, the density of the object could be calculated. In this instance, the more water displaced by the wreath, the greater the gold content of the wreath. Archimedes himself set out the basic principle, now known in hydrostatics (the study of the pressures liquids exert or transmit) as "Archimedes' principle," in his treatise "On Floating Bodies," but he did not describe his bathing experience. The "Eureka" story is typical: Tradition reported Archimedes' more popularly understandable discoveries in the form of a concise quotation. "I found it" may be compared to his statement "Give me a place to stand and I shall move the Earth," thereby concisely expressing the power of a lever.

Other mechanical inventions illustrating Archimedes' skills at applying abstract mathematical and geometrical principles to mechanical inventions include a screw for raising water (*kochlias*), and spheres (*sphairai*) on which the movements of stars and planets were modeled. One of these spheres apparently illustrated various constellations; the other one seems to have been a genuine planetarium showing the orbits of the five known planets, the Sun, and the Moon. These two spheres were reportedly seized as booty by Marcellus and taken to Rome: one was dedicated to the goddess Virtue, the other Marcellus kept for himself. One of Archimedes' more interesting inventions was an odometer. That device seems to have consisted of a cart with gears (attached to a wheel) that dropped a ball into a container after a specific distance had been traveled. Archimedes was also said to have improved, in some way not specified, the hurling capacity of the catapult.

During his life before the siege of Syracuse, Archimedes composed a body of treatises (more than twenty-seven, complete or partial, have survived) exploring problems of geometry and mathematics. His writings indicate particular interests in calculating the area and volume of geometric figures (the area under the arc of a parabola, for example) and the behavior of irregularly shaped geometric bodies (a trapezoid, for example) in liquids. Among his more stimulating and complex treatises is "The Sand Reckoner," in which he not only describes a new and effective method of calculating the diameter of the Sun but also hypothesizes how many grains of sand would be necessary to fill the known cosmos. As several commentators have observed, the apparent absurdity of Archimedes' goal is, fundamentally, little dif-

AN ANCIENT MECHANICAL ENGINEER

One of Archimedes' most useful and influential inventions was the water screw (*kochlias*). King Hieron II of Syracuse commissioned the construction of a gigantic ship, named the *Syracusia*. This wooden ship was so large that leakage was a problem. Archimedes invented a device designed to remove bilge water from the hull of this and other large ships. "Archimedes' screw" consisted of a revolving metal screw blade placed within a cylinder. A fresco from ancient Pompeii shows how the screw was powered: continual treading on spokes attached to the cylinder of the screw. A machine that efficiently raised water from one level to another, this device could be (and, in many rural areas of the world today, still is) employed to lift water from a lake, stream, or river to an irrigation canal. In the ancient Mediterranean world, the screw was used for irrigation in Egypt and to drain water from mines in Spain.

Another practical invention, utilizing the principle of leverage, was the large-scale crane. In addition to their use in defense at Syracuse to drop weights on attacking ships and to lift the prows of the ships, these large wooden structures could be used for more peaceful purposes. Wooden cranes of the type Archimedes invented, employing pulleys and ropes, and operated, in several known instances, by men on a treadmill, were adopted by the Romans for constructing tall buildings and loading and unloading ships.

Archimedes' discovery of the principle of water displacement led to another invention: a more efficient water organ, in which air compressed above water in a chamber was channeled to the organ's pipes of differing length, thus producing different tones. Among Archimedes' lost treatises was the book *On Sphere-Making*. That book seems to have dealt with the construction of the invention of which Archimedes was most proud: a spherical planetarium demonstrating in one revolution how the independent motions of the Sun, Moon, and planets moved relative to the fixed stars as they do in one day. In addition, the planetarium enabled observation of the phases and eclipses of the Moon. Archimedes' planetarium is frequently mentioned by ancient authors, for some of whom it was the physical proof of Archimedes' genius.

ferent from modern scientists' attempts to estimate the total mass of the universe. In many respects, Archimedes' most interesting treatise is "The Method," wherein he sets out his understanding of theoretical mathematical and geometrical reasoning and its practical applications.

Archimedes was executed in 212 B.C.E., reportedly because his preoccupation with his studies—he was working out geometrical problems by drawing in the sand, the ancient equivalent of a blackboard—did not permit him to obey a Roman soldier's command. His grave marker, a sphere within a cylinder, illustrated one of his proudest accomplishments—calculating the ratio of 3:2 between a cylinder and sphere. That tomb was rediscovered, in a forgotten thicket at Syracuse, by the Roman orator and politician Cicero in 75 B.C.E.

IMPACT

Archimedes reputedly sent copies of his theoretical studies to the library in Alexandria, Egypt, but no master edition of his works was, it seems, compiled and available for distribution. Thus, Archimedes' treatises do not appear to have been widely known or studied until the late fifth century C.E. Isidore of Miletus then collected and studied several of Archimedes' treatises, especially those bearing on his own interests as an architect. (He was the master builder of the emperor Justinian's great church of Hagia Sophia in Constantinople.) Commentaries on some of Archimedes' treatises were composed by the Byzantine Greek scholar Eutocius about 510 C.E. A number of Archimedes' works were preserved in Arabic by the translations of the Islamic scholar Thābit ibn Qurra (836-901), to return to European consciousness by about 1180 through medieval Latin translations. All of the known works of Archimedes were published, in Greek with a Latin translation, at Basel in 1544 by Thomas Gechauff. Four decades later, Galileo invented a method for weighing metals in water and air.

—Paul B. Harvey, Jr.

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See also: Giovanni Branca; Ctesibius of Alexandria; Galileo; Al-Jazarī; Al-Khwārizmī; Joseph-Michel and Jacques-Étienne Montgolfier; Evangelista Torricelli.

ARISTOTLE

Greek philosopher

Aristotle, history's first empirical scientist, introduced the scientific method, the foundations for scientific taxonomy, formal categorical logic, the first scientifically grounded monotheism, and many other metaphysical beliefs still undergirding modern thought in the twenty-first century.

Born: 384 B.C.E.; Stagirus, Chalcidice, Greece
Died: 322 B.C.E.; Chalcis, Euboea, Greece
Primary field: Biology
Primary inventions: Biological taxonomy; scientific method

EARLY LIFE

Little is known about the early life of Aristotle (EHR-ihs-taw-tuhl). The only sources available, other than a few mentions in ancient fragments, are a page of text from Dionysius of Halicarnassus, written presumably two hundred years after Aristotle's death, and Diogenes Laërtius's entry on him in his *Philosophoi biol* (lives of the philosophers), written in the third century C.E. It is reasonable to suppose that, given this dearth of biographical information, he was not considered an important person during his lifetime, but only came to be recognized as such long after his death.

In 384 B.C.E., Aristotle was born in the northern Hellenic polis of Stagirus, a colony of the polis of Chalcis. His mother, Phaestis, was a wealthy descendant of one of the original colonizers, and this gave the family excellent social standing. His father, Nicomachus, was the friend and physician of Amyntas II, king of Macedonia, father of Philip, and grandfather of Alexander the Great. This link to Macedonia would be a problem for Aristotle later in life.

His early education would have been in accordance with standard upper-class Hellenic practices, but probably also included training in medicine, because of his father's profession. This training did not last long, as his father died when Aristotle was still young, leaving him to be raised by his uncle Proxenus. In 367, at the age of seventeen, Aristotle left Stagirus and went to Athens to study with Plato at his Academy. Plato's "school" was a gathering place for the intellectually minded, regardless of their particular interests. Plato encouraged the study of the sciences, especially mathematics and astronomy. Aristotle remained at the Academy, studying, learning, and eventually lecturing, for twenty years, until Plato's death in 347.

LIFE'S WORK

Plato's Academy was the first real institution of higher education in history, although it did not much resemble the university as it is known today. It is important to understand that at this time there was really only one discipline: philosophy. People were doing mathematics and studying poetry, of course, but the very concept of a discipline had not developed yet. The disciplines as they are now known are all offshoots from philosophy, most of which would not separate from philosophy until after the Renaissance, around 1400 C.E. Because there were no other schools, the Academy was a beacon for all the greatest minds of the time, gathering all manner of intellectually curious and adept thinkers.

Aristotle's time at the Academy would have thus been spent studying and teaching not only what are now considered the traditional philosophical subjects of reasoning, metaphysics, epistemology, aesthetics, ethics, and political theory but also many subjects that are no longer considered to be philosophy: mathematics, rhetoric, poetics, and what passed for natural science at the time. Indeed, it was in rhetoric that Aristotle first distinguished himself, writing in about 360 B.C.E. a dialogue titled *Gryllus*, in which he attacked the views of a contemporary rhetorician, Isocrates. Curiously, a famous response to this work criticized Aristotle for the time he wasted in collecting proverbs—evidence that by this time he was already hard at work collecting things for analysis and categorization. The work known today as Aristotle's *Rhetoric*, *Technē rhetorikē*, was begun at this time, and he continued to refine those ideas for most of his life.

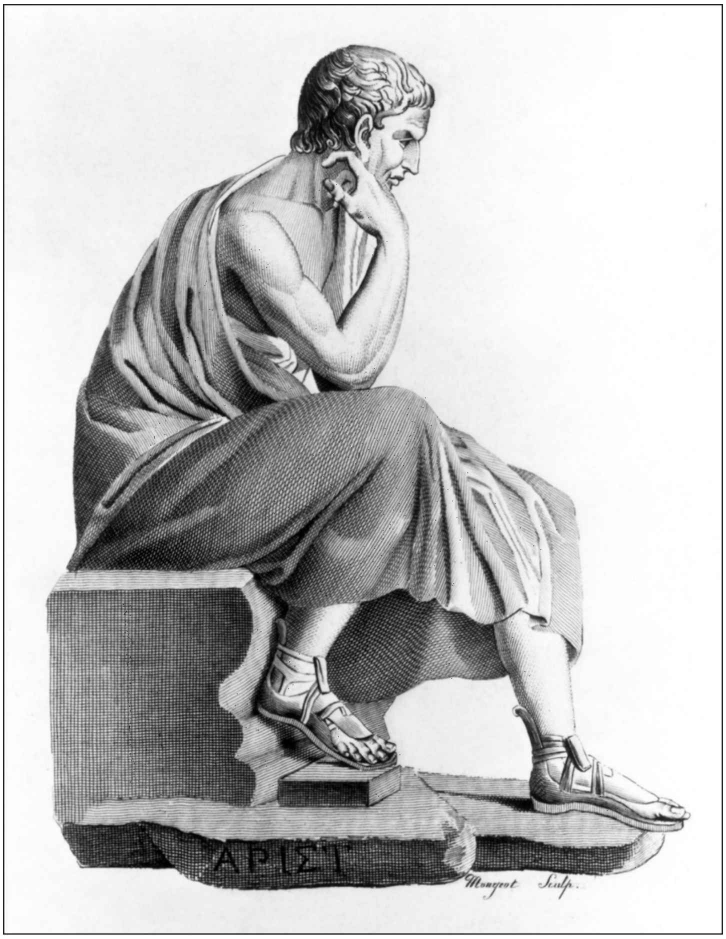
Upon Plato's death in 347, Aristotle left Athens. He traveled around the eastern Aegean and began collecting and studying zoological specimens in earnest. It is not known why he left Athens, but as Plato's star pupil, he would probably have expected to become head of the Academy. He did not. There are stories that tell of him leaving in bitterness and disgrace because of this. However, there are also stories relating a rising anti-Macedonian sentiment in the Athenians at this time, due to the encroachment of Macedonia into Greek territory. Not being an Athenian citizen—then or ever—Aristotle may have felt uncertain about his safety.

The work he did during this Aegean period was to be his most far-reaching, for this was the work that would form the foundations of the empirical natural sciences. For unknown reasons, Aristotle returned to his home in

Stagirus after a few years and remained there until 343, when Philip of Macedonia summoned him to Mieza to tutor his son Alexander. In 340, for perhaps political reasons again, Aristotle left Alexander and returned to Stagirus to continue his scientific and philosophic work. In 335, in a supposed bid to take over as head of the Academy, Aristotle returned to Athens. Unsuccessful in his attempt to head the Academy, he founded his own philosophic school: the Lyceum. He would remain in Athens until a year before his death in 322, when, again, renewed anti-Macedonian sentiment drove him to his family's home in Chalcis.

The work done in his last Athenian period was probably the most extensive of his life. At this time, he would have done his most important philosophical and systematic thinking, bringing new insights to his earlier scientific work and blending that with his developing logic. The results would shake the world and form the basis of all thought for more than a thousand years. No other thinker has had as much influence on Western civilization and thought as Aristotle. Aristotle is the only person in history to have founded two new sciences from the cauldron of philosophy: logic and biology. In addition, in order to make biology a viable science, he had to develop the idea of what a science should be. Without Aristotle, the natural sciences would not have the form they do now.

Aristotle's works deserve a note here. What is now considered to be Aristotle's corpus is only a fraction of his actual output. Most of his work has been lost, and all of his writings designed for the consumption of others is gone. What remains are simply notes developed for his lecturing at the Lyceum. It cannot be said when the ideas in these notes were first formed, when the lecture notes were written, or how extensively or often (if at all) they were revised. The works that remain are now believed to have been originally published in about 60 B.C.E. by Andronicus of Rhodes, the last head of the Lyceum. The selection, ordering, and editing were certainly at his own hand, and not that of the long-dead Aristotle.



Aristotle. (Library of Congress)

IMPACT

It is not an exaggeration to say that there has never been an individual as influential on human civilization as Aristotle. To detail the impact of his thought would be to detail the history of European thought since his time. By the Renaissance, Aristotle's ideas had been considered received truth for some time; in Europe, there was no other authority, other than the Church, that received such unquestioning acceptance. The ideas and terminology used by him and his students at the Lyceum would become the framework for all further philosophic and scientific work.

The very idea of a scientific method is thoroughly Aristotelian. Before his work, science as it is known today did not exist. No one was collecting empirical data and reasoning about it. He introduced the idea that data is primary and theory must come afterward and developed the framework for theorizing and categorizing data. The biological work he did in the fourth century B.C.E. was to remain precisely how biology was conceived up until the nineteenth century C.E.

ARISTOTLE'S BIOLOGICAL TAXONOMY

Aristotle devised and began to develop the first biological taxonomy during a tour of the eastern Aegean in 347 B.C.E. While taxonomies of other things were quite common at the time, no one had yet attempted to classify living things in any systematic way. Aristotle's taxonomy was not merely a means of organizing knowledge of the animal kingdom but was actually the attempt to describe the universe as it really is; in other words, his taxonomy was a description of the "natural" places of everything in the universe.

The biological level of this taxonomy was divided into two parts: animals and plants. Of these two parts, Aristotle focused only on animals. The current botanical taxonomy actually originated in the work of Theophrastus, Aristotle's best student and successor, who worked, of course, from Aristotle's example and within his metaphysical system.

Aristotle's divisions of genera and species were based on both his metaphysical schema of the universe and observation. Grouping animals based on their habitats and bodily structures, Aristotle concluded there were two basic types of animal: those with (red) blood, and those without. These classifications line up fairly well with current categories of vertebrates and invertebrates. Of the blooded animals, there were five kinds: land mammals, birds, reptiles/amphibians, fish, and cetaceans (dolphins, porpoises, whales). Those that had no blood were divided as such: arthropods (insects and spiders), crustaceans, shellfish, soft animals such as octopuses and squid, and then plantlike animals such as corals and jellyfish.

Aristotle's biological taxonomy was fairly quickly adopted by everybody with any interest, partly because it was the only one in existence and partly because it was so detailed. Using habitat and body structure to classify these animals also meant that he had gathered much information on their habits, anatomy, reproduction, life cycles, sustenance gathering and feeding, rearing of young, and so on. With Thomas Aquinas in the thirteenth century C.E. bringing Aristotle's metaphysical hierarchy into the Roman Catholic Church, Aristotle's science became the official worldview of the Church, and thus of Western culture. Because of this adoption by the Church, Aristotle's taxonomy was immune to rejection or revision for hundreds of years—until the Church's power was weakened enough for science as it is now known to develop.

After the Renaissance was made possible by the decline in the Church's power, numerous biologists began expanding on Aristotle's taxonomy, but it was not until Carolus Linnaeus (1707-1778) began to distinguish plants by their sexual parts that the taxonomic system used today began to take its more familiar shape. The age of exploration brought knowledge of previously unknown organisms that had to be classified. With this influx of data and the freedom to study it, biological taxonomy finally came into its own, but one can still see the influence of these men in the present taxonomic use of Aristotle's Greek and Linnaeus's Latin.

Philosophically, Aristotle was even more influential. His development of categorical logic as a tool for scientific reasoning and a method of scientific taxonomy worked so well that it was thought complete until the nineteenth century C.E. He introduced the very ideas of genus and species, matter and form, essence and accident, energy and potentiality, final causes, virtue ethics, and the first scientifically justified monotheism. Without these ideas, the Church would not have developed as it did, nor would have science or philosophy or Western culture.

—*Leslie C. Miller*

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See also: Roger Bacon; Giovanni Branca; Ctesibius of Alexandria; Galileo; Otto von Guericke; Zacharias Janssen; Antoni van Leeuwenhoek; Sir Isaac Newton; Ptolemy.

SIR RICHARD ARKWRIGHT

British manufacturer

Arkwright played a crucial role in the Industrial Revolution by devising, manufacturing, and exploiting a device that mechanized one of the oldest traditional crafts, spinning yarn.

Born: December 23, 1732; Preston, Lancashire, England
Died: August 3, 1792; Cromford, Derbyshire, England
Primary field: Manufacturing
Primary invention: Spinning frame

EARLY LIFE

Richard Arkwright was the sixth of seven surviving children of Thomas Arkwright (1691-1753) and Ellen Hodgkinson (1693-1778). The family was poor and Arkwright received little formal education, but two of his elder sisters attended Blue Coat School and passed on what they learned to their younger siblings. In his early teens, he was apprenticed to a barber in the nearby town of Kirkham, but moved to Bolton-le-Moors in 1750, initially to work for the wig maker Edward Pollit, and then, briefly for Pollit's widow. By 1755, he had set up a barber's stall in a passage leading to an inn, shaving chins for a penny. On March 31 of that year, he married Patience Holt, the daughter of a schoolmaster, and promptly borrowed £60 from her father to expand his business. The couple's only child, also named Richard, was born on December 19, but when Patience died on October 6 in the following year she was buried with her mother under her maiden name.

On March 21, 1761, Arkwright married Margaret Biggins of Pennington, and repaid the debt he owed his first wife's father with the bulk of an inheritance she had received; he invested the rest in an inn, the Black Boy, whose publican he became. The business soon failed, and he returned to wig making, also dabbling—as most nineteenth century barbers did—in bleeding and tooth extraction. He began buying hair on a large scale, ostensibly making use of a secret dyeing technique in making his wigs. Margaret bore him three children, one of which—Susanna, born December 20, 1761—survived into adulthood.

LIFE'S WORK

Arkwright's invention of the spinning frame was understandably shrouded in secrecy and inevitably embroiled in controversy. The search for a means of mechanizing the process had been urgent for some time, but an earlier machine patented by Lewis Paul and John Wyatt in 1738 had proved impracticable. Thomas Highs of Leigh subsequently claimed to have devised the innovations that he carelessly confided to Arkwright in conversation, but what is certain is that in 1767 Arkwright formed an association with a clockmaker named John Kay, who made him a model of a spinning machine, which the two of them began to hawk around.

After failing to find backers in Manchester and Preston, Arkwright and Kay took two of their relatives—the former publican John Smalley and the merchant David Thornley—into their partnership in order to build and exploit a full-scale machine in Nottingham. They petitioned for a patent on June 8, 1878, but it was not granted until July 3, 1769, perhaps because they had trouble scraping together the money to pay the fee. Thornley had to sell part of his share to Smalley when his own capital ran out, and a new fifth share in the association was taken by Samuel Need and Jedediah Strutt, who provided the finances necessary to construct a horse-drawn mill, to be managed by Arkwright and Thornley.

The Nottingham mill did not start production until Christmas, 1772, by which time the partners had already commissioned the construction of a new mill at Cromford in Derbyshire, driven by waterpower. The original intention had been to spin yarn for stockings—Strutt was already involved in that trade—but the yarn produced by Arkwright's machine was both thin enough and strong enough to serve as the warp on a loom, so the Cromford mill began to produce calico with an efficiency that astonished its owners and their rivals. Arkwright set up his headquarters there and began to expand his operation. Strutt joined forces with other entrepreneurs to lobby Parliament to reduce excise duties on British cotton goods; when they were successful, the Cromford mill's profits increased considerably, and the partners set out to dominate the trade, applying for further patents that would establish a virtual monopoly. The result of these moves was an intense competition, which was also reflected within the partnership as Arkwright attempted to squeeze out his associates.

Arkwright's legal wrangles came to a head in July, 1781, when he sued nine other manufacturers for breaching his patents. It was during this period that Highs came forward to lay charges of theft against Arkwright—charges that were never substantiated but probably contributed to the eventual result of the conflict, which was the cancellation of Arkwright's patents in 1785. By that time, however, most of Arkwright's original partners were dead and he was exceedingly rich, owing to the huge profits he had made during the previous decade. The cancellation of the patents initiated a free-for-all that brought about a boom in the cotton industry throughout the north of England.

Arkwright appears to have been just as desperate to make social progress as economic progress, although he labored under the handicap of a personality that did not allow him to make friends easily and often alienated those he had. Jedediah Strutt introduced him to Erasmus Darwin, enabling him briefly to associate himself with Darwin's prestigious Lunar Society—James Watt, another prominent member of the group and the inventor of the steam engine, was also a tireless lobbyist for the protection of patents—but Arkwright soon quarreled violently with Darwin, as he seemed to have done with many of his new acquaintances. He was, of course, deeply resented by the landed gentry of Derbyshire, who mocked him relentlessly as an upstart. He bought Willersley Manor, near Cromford, in 1782, and bought the manor of Cromford itself in 1789.

Arkwright also bought a town house in London in 1789 but actually lived for most of his later life in Rock House, situated on a hill overlooking his Cromford mills, while he commissioned and supervised the construction of a grandiose stately home he named Willersley Castle. He did not live long enough to make much use of it, dying in the year of its completion, 1792, but it accommodated his son and, in their turn, his further descendants, until 1925. In the meantime, he was knighted in 1786 and became high sheriff of Derbyshire in 1787. In 1790, he introduced the first steam engine into his works at Nottingham, thus completing the foundations of the revolution in textile production that changed the face of England in the early nineteenth century.

THE SPINNING FRAME

The earlier spinning machine credited to Lewis Paul and John Wyatt substituted two mechanically rotated rollers for the wheel and distaff that had been used in spinning since time immemorial—to the extent that a famous English traditional rhyme begins "When Adam delved and Eve span." The Paul-Wyatt machine did not work very well, because the machine could not compensate, as a hand spinner instinctively did with skillful gestures, for two problems that inevitably arose as the process went on: the increasing diameter of the accumulated thread on the "distaff roller" and the tendency of the thread to become twisted in the drawing space.

Sir Richard Arkwright's machine solved both these problems, the first by moving the distaff roller so that the surface of the accumulating thread maintained a constant distance from the "wheel roller," and the second by weighting the upper roller so as to prevent the instabilities that caused twisting. These were minor adjustments, involving no particular technical complexities, but they were crucial to the success of the machine, in the sense that it could work for long periods without having to be stopped to correct problems. The quality of the yarn it produced was remarkably consistent—more consistent, in fact, than the thread produced by all but the most expert hand spinners—and that made it ideal for use as warp on a loom, enabling mechanized looms to produce not only cloth at a far greater speed than hand looms could produce but also cloth of a more even texture and quality. Such efficiency and consistency of manufacture was the essence of competent mass production, and Arkwright's contribution to that evolution was highly significant in historical terms.

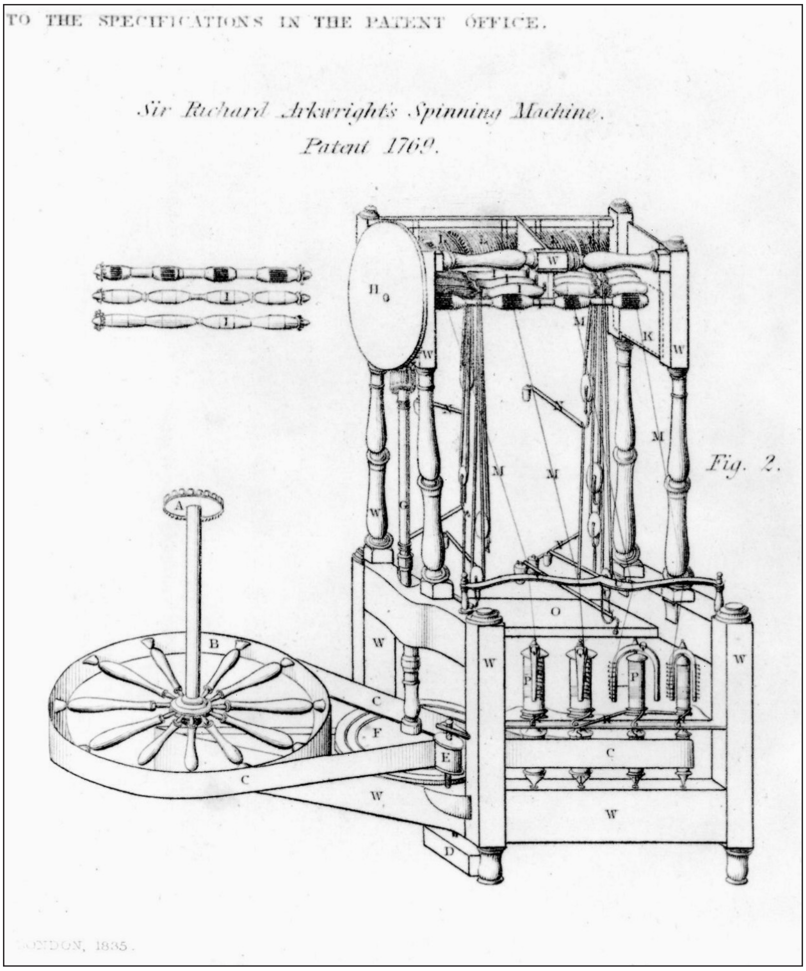
TO THE SPECIFICATIONS IN THE PATENT OFFICE.
Sir Richard Arkwright's Spinning Machine.
Patent 1769.
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Fig. 2.
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LONDON, 1835.

Sir Richard Arkwright's spinning frame. (Library of Congress)

IMPACT

Arkwright was the archetypal "self-made man" and became an important exemplar to future inventors and businessmen for that reason. Although he suffered all through his life from asthma, he insisted on working from 5:00 A.M. to 9:00 P.M. every day, and his taciturnity became as legendary as his industry. A devotee of retrospective psychology might be tempted to diagnose him as a victim of Asperger's syndrome, but the Victorian writers who appointed him a pioneering hero of the Industrial Revolution approved wholeheartedly of his dour determination and obsessive ruthlessness, and would have considered his combination of vaulting social ambition and churlish unsociability quite normal.

If Arkwright became a hero to the industrialists who followed him, he also became a villain in the eyes of subscribers to the "rage against the machine" carried forward by active Luddites and the Romantic writers who tended to equate industrialization with spoliation. One of his mills was said to have been demolished by rioters, while police and military forces looked on sympathetically, although the reports might have been exaggerated.

Arkwright's spinning frame, often known as a water frame because of its particular application at Cromford, was not the only one to be invented at the time—James Hargreaves's so-called spinning jenny was virtually contemporary. If Highs can be believed, Arkwright might not actually have originated the idea of his own machine, but he was the determined opportunist who carried that machine all the way through the developmental process to full-scale industrial production, joining forces with Jedediah Strutt along the way to change the political-economical environment so as to allow that production to flourish.

Arkwright was, in essence, the man who successfully reinvented the wheel—spinning being, for most of its history, as significant an application of the wheel as wheeled transport, whose utility was limited until roads improved sufficiently to accommodate such vehicles.

—*Brian Stableford*

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See also: Edmund Cartwright; James Hargreaves; John Kay; Sakichi Toyoda.

EDWIN H. ARMSTRONG

American electrical engineer

Armstrong developed a number of key inventions in radio broadcasting, including the superheterodyne circuit, the regenerative circuit, and frequency modulation.

Born: December 18, 1890; New York, New York
Died: January 31, 1954; New York, New York
Also known as: Edwin Howard Armstrong (full name)
Primary fields: Communications; electronics and electrical engineering
Primary inventions: Frequency modulation (FM); regenerative circuit; superheterodyne circuit

EARLY LIFE

Edwin Howard Armstrong (AHRM-strahng) was a New York City boy born and bred. His father, John Armstrong, was one of the senior executives of the American branch of Oxford University Press. This position required an annual visit to London to confer with his superiors in the home office, and he would take the opportunity to acquire books that simply were not available in the United States at the time. As a result, young Edwin was exposed to a wide variety of books, including *The Boy's Book of Inventions* (1899), which sparked his fascination with gadgetry.

At the age of seven, Armstrong was stricken with Sydenham chorea (St. Vitus's dance), a movement disorder associated with rheumatic fever in which the person's muscles twitch and jerk uncontrollably. At the time, doctors believed that the disorder was psychological in origin, a nervous response to a sudden fright or other disturbance of the emotional equilibrium. The treatment was to keep the child quiet and avoid exposure to excitement or stimulation, which resulted in his being kept at home and tutored in his studies by a maternal great-aunt for two years. During this time, the family relocated to the suburbs in hopes of finding a more healthful environment for the boy.

Suburbia also proved an environment in which Armstrong could indulge his fascination with exploration more widely than was possible in the city. He developed a fondness for heights, climbing the steep escarpments of the Palisades. As a teenager, he would take his toolbox to a nearby road and wait for an automobile to break down so he could have the challenge of fixing it. He also became increasingly fascinated with radio, and after acquiring the necessary equipment he began making amateur transmissions to a number of friends in the area. He formed a friendship with inventor Charles Underhill and regularly visited to pick the man's brain.

In 1909, Armstrong entered Columbia University's electrical engineering program, commuting from home each day on a bright red motorcycle, a high school graduation present. This arrangement permitted him to indulge his growing fascination with speed and to continue his experiments in his home radio laboratory. His mastery of the subject of radio quickly surpassed that of many of the instructors, and he once severely annoyed a visiting professor from Cornell University by publicly challenging misinformation in a lecture.

LIFE'S WORK

In 1912, while still a student at Columbia, Armstrong was studying some of the peculiarities of the Audion, or triode vacuum tube, invented by Lee De Forest. At the time, its use as an amplifier was still so tricky that many wireless telegraph operators used a crystal detector (a sort of crude point-contact transistor) to pick up and amplify radio waves. When Armstrong realized that the Audion was oscillating in a steady rhythm, he had the insight that a person might be able to feed the current from the plate back through the grid, further amplifying it with each iteration. However, the exact method of doing this eluded him for some time, until he was vacationing in the Green Mountains of Vermont and had the key insight. He hurried home and set to work in his laboratory. On September 22, he made a workable regenerative circuit.

The principle of regeneration transformed the triode from a rather iffy competitor to a reliable powerhouse. Regeneration rapidly became a mainstay of every electronic circuit that required amplification, from radios to long-distance telephone lines to stereos and radar. Even after the transistor dislodged the vacuum tube from pride of place, the regenerative circuit continued to hold its own as a key element of electronic devices and was one of the earliest to be laid out as an integrated circuit, or microchip.

Although Armstrong's first invention would easily have secured his fame, his restless mind would not be satisfied with past achievements. He relentlessly explored all the features of the regenerative circuit and discovered that if one tuned it a particular way, it could become not only a receiver and detector of radio waves but also a transmitter. Moreover, it could produce a continuous carrier wave suitable for voice transmissions, a feat that previously had required a large alternator that rotated at extremely high speeds.

However, because Armstrong was still a student at the time, his father saw no reason to spend the $150 to register a patent on his ideas. In his father's eyes, the patent could wait until his son had finished his education. This parsimony would be the root of a lifetime of grief for Armstrong because it deprived him of the priority claim on his invention that would have spared him dozens of lawsuits against De Forest and others in the radio industry. When Armstrong graduated and applied for his patent, he further compounded the error of delay by having the patent written in a restrictive form rather than covering as many applications of his ideas as possible, leaving ample room for others to encroach upon his work without actually infringing, and thus being able to profit without needing to pay license fees to him.

Edwin H. Armstrong. (Smithsonian Institution)

When the United States entered World War I in 1917, Armstrong joined the U.S. Army Signal Corps, in which he tested the early radios used in airplanes. Because Germany was rumored to be using very high-frequency radio transmissions to evade detection by Allied signal intelligence, Armstrong worked on a technique to detect and decode these signals by using a second frequency to create a third frequency within the range of human hearing. This superheterodyne circuit would subsequently become the basis of precision radio tuning. While early radios had to be tuned by a specialist, a superheterodyne radio needed only three knobs, making it possible for ordinary people to operate them and thus making way for the golden age of radio.

Armstrong's next great breakthrough would come in the 1930's, when he developed a workable system of frequency modulation, or FM. However, when he presented the technique to the Radio Corporation of America (RCA), the company did nothing. In fact, RCA executive director David Sarnoff was planning to use the technique for the sound channel of television, which was in development at the time, but he did not want to make instantly obsolete the entire user base of amplitude modulation (AM) radios. Frustrated, Armstrong then created his own experimental FM station, and then an entire network of FM stations, the Yankee Network.

During World War II, Armstrong worked on various projects for the military, in particular techniques for allowing radars to distinguish between friendly and enemy aircraft based on their echo return patterns. After the war was concluded, he decided to take to task several companies, including RCA, for their use of his FM patents without paying royalties. RCA in particular battled him relentlessly, since it was under Sarnoff that the company bought patents outright rather than pay royalties on them.

As Armstrong's financial resources dwindled, his nerves frayed and finally gave way altogether. On January 31, 1954, he penned a letter to his wife, put on his coat and hat, and opened the window of his thirteenth-floor New York apartment and stepped out to his death. Although Sarnoff would always claim that he meant his old

FREQUENCY MODULATION

It was the desire to get rid of the annoying crackle of radio static that led Edwin H. Armstrong to invent frequency modulation, commonly abbreviated as FM. Armstrong's work began when David Sarnoff of Radio Corporation of America (RCA) expressed a desire for a device that would eliminate the static that plagued radio broadcasts. This static came from random electrical discharges in nature, mostly lightning but to a lesser degree sunspots and other solar phenomena.

Sarnoff had apparently imagined a sort of filter, but Armstrong envisioned a completely new approach to radio broadcasting. Ever since Reginald Aubrey Fessenden made his first voice broadcast in 1901, radiotelephony had imposed the information of the signal onto the amplitude of the carrier wave. However, Armstrong realized that if he could find a way to impose the information on the frequency of the waves, he could create a signal that would not be affected by this constant random electrical noise.

Creating a workable system of FM radio was not easy. Mathematician John R. Carson had claimed that radio theory proved it impossible to successfully impose information on the frequency of a carrier wave. However, Armstrong recalled that John Ambrose Fleming, technical adviser to Guglielmo Marconi, had claimed that the only way to operate a radio was by generating blasts of static to represent the dots and dashes of Morse code. The supposed impossibility of FM only served to spur Armstrong's efforts, until he realized that the key to a workable FM system lay in increasing the bandwidth of the signal far beyond that occupied by an AM station, thus giving the signal space to be imposed upon the frequency.

On December 26, 1933, Armstrong registered a patent on FM written in the broadest possible language. The following year, he approached Sarnoff with a finished device, but Sarnoff chose not to adopt it at the time. Although the obvious reason for his reluctance was that he wished to avoid instantly rendering obsolete an entire user base of amplitude modulation (AM) radios, Sarnoff in fact planned to use FM for the audio track for television then in development.

During Armstrong's lifetime, FM saw minimal commercial development. His own Yankee Network met with continual bureaucratic roadblocks from the Federal Communications Commission (FCC), the final one being a shift in the portion of the radio spectrum allotted to FM radio broadcasts. However, in the decades that followed, FM would become of increasing importance as high-fidelity radio receivers led to a demand for clear transmission of complex musical forms. By the late 1970's, almost all consumer radios had both AM and FM band capability, and by the end of the 1980's music stations were increasingly moving to FM, leaving AM entirely for news and talk stations. One of the last holdouts was WLS of Chicago, which in 1989 played its last rock record and became entirely a talk station.

friend no ill will, there was evidence that he felt somewhat uneasy about his own contribution to Armstrong's state of mind. Armstrong's widow subsequently won all the patent infringement suits, including the one with RCA, on behalf of her husband's estate.

IMPACT

By making the radio receiver into an appliance that anyone could use, Edwin Armstrong transformed radio into an entertainment medium. However, the lawsuits he launched first against Lee De Forest and then against David Sarnoff's company left a cloud of acrimony over his legacy.

—*Leigh Husband Kimmel*

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See also: Ernst Alexanderson; Karl Ferdinand Braun; Lee De Forest; Reginald Aubrey Fessenden; Guglielmo Marconi.

ARTHUR JAMES ARNOT

Australian electrical engineer

Arnot is credited with the invention of the electric drill. His invention was quickly modified by others, who built both large industrial machines and small hand tools for the average handyperson.

Born: August 26, 1865; Hamilton, Scotland
Died: October 15, 1946; Castle Hill, New South Wales, Australia
Primary fields: Electronics and electrical engineering; mechanical engineering
Primary invention: Electric drill

EARLY LIFE

Arthur James Arnot was born in Hamilton, Scotland, on August 26, 1865. His mother was Elizabeth Helen Macdonald Arnot, and his father was William Arnot, a commercial agent. Arthur attended Hutchisontown Grammar School and Haldane Academy in Glasgow, and in 1881 he began studies at the West of Scotland Technical College in Glasgow. He moved to London to continue his studies part-time while working for an electrical engineering company. In 1885, he became an assistant engineer at the Grosvenor Gallery power station, a privately owned generating station established by Sir Coutts Lindsay to provide electricity to light an art exhibit. The station was run by the engineer Sebastian Ziani de Ferranti, himself only twenty-three years old at the time Arnot was hired. Ferranti, a prolific inventor, made great improvements to the station's ability to transmit high-voltage power. By 1886, he had made the station the largest and most efficient supplier of public electricity in England. Working with Ferranti on an expanding project gave Arnot an unparalleled chance to experiment and innovate, and to learn the new business of producing and supplying electricity.

Arnot left the United Kingdom for Australia in 1889, under a two-year contract to build a large alternating-current-generating plant for the newly formed Union Electric Company in Melbourne, a city in the state of Victoria. He spent nearly the rest of his career and life in Australia.

LIFE'S WORK

Arnot designed and oversaw the building and management of Melbourne's Spencer Street Power Station, a coal-fired station that provided power for the city and sold surplus power to other municipal distributors. In March, 1891, the city council named Arnot Melbourne's first electrical engineer. He held the post until 1901, making occasional extended trips to England and the United States to keep up with new innovations in electrical engineering. In August, 1891, Arnot married Cornelia Ann, the daughter of one of the city councilors. At this time, the main use of municipal electricity was for lighting (electrical appliances and machines had not yet been developed). In 1891-1892, Arnot installed an array of electric streetlights in the city, replacing the gaslights that had been installed in the 1850's. He modeled his "series arc and incandescent system" on the system already in use in London and the United States. Soon, the central business district of Melbourne was illuminated with electric lights from a central source—a first in Australia.

Electricity generation at the end of the nineteenth century was a dangerous and largely unregulated enterprise, and many entrepreneurs, with varying degrees of expertise, set up their own generating stations and sold power to their neighbors. In 1896, Arnot drafted an Electric Light and Power Act that was passed by the parliament of the state of Victoria. Under the terms of this act, people could generate power for their own use but could not supply to others without a license.

Arnot had a long and distinguished career as an engineer in Melbourne, but his most lasting achievement as an inventor came during his first year in Australia. While he was engaged in the construction of the Union Electric Company's electrical plant, he sought a better way to dig coal and to drill foundation holes in rock. On August 20, 1889, he along with mining engineer William Blanch Brain and Frank Baker patented the world's first electric drill, which they called "an improved electrical rock-drill, coal-digger, or earth-cutter." Although the patent clearly names all three men (in fact, Brain's name appears first), Arnot is usually given sole credit for the invention. Arnot also worked on refinements to the electric motor that powered his drill, and in 1891 he was granted a patent for an improved alternating-current (AC) motor. Unlike the small hand drills common in the twenty-first century, Arnot's drill was a large industrial machine.

Known as a hardworking and creative man, Arnot was profiled as one of several "Coming Men" in a series of articles in the Australian science journal *Table Talk* in 1893. In 1899, he was elected a member of the Institution of Electrical Engineers in London and to the presidency of both the Victorian Institute of Electrical Engineers and the Electrical Association of New South Wales. During his time as Melbourne's electrical engineer, it seemed that direct current (DC) was superior to alternating current, and Arnot oversaw a substantial expansion of the DC grid during his tenure. With the later development of improved AC motors, however, it became apparent that alternating current was preferable, and a large amount of money and resources were spent in rewiring. In 1899, Arnot traveled to England and the United States to gather more opinions in the contentious battle between DC and AC.

In 1901, Arnot left Melbourne for Sydney to take the position of Australasian manager for Babcock and Wilcox, a large American firm that designed, engineered, built, and managed large steam-powered electrical generating stations. Babcock and Wilcox had provided some of the boilers for the Spencer Street Power Station. In this position, Arnot helped smaller cities and private power companies throughout Australasia build and manage electrical power plants using Babcock and Wilcox designs and equipment.

On September 29, 1904, Arnot's son Frederick Latham was born. Frederick went on to become a university lecturer in natural philosophy and later physics. Arnot joined the city council while in Sydney, and he was implicated in a corruption scandal involving the council's contract for a steam-raising plant. It was charged that he had paid a bribe to have his company's boilers chosen for the project. He was formally censured by Judge John Musgrave Harvey in 1928. Arnot retired from Babcock and Wilcox the next year.

During his years in Sydney, Arnot also participated in the military. He was commissioned a lieutenant in the Submarine Mining Company, Victorian Engineers, in 1894, when he was twenty-nine. The Victorian Engineers was part of a volunteer force defending the colony of Victoria. (The Commonwealth of Australia would not be established until 1901.) The Submarine Mining Company set explosives on the ocean floor and triggered them from shore. In 1915, near the beginning of World War I, Arnot joined the Australian Engineers, Australian Military Forces. At age fifty, he was unable to join his countrymen fighting with the Allies at the western front, but he could lend his expertise as an engineer. In 1916, he took command of the Sydney field companies and reinforcement camps. He retired from the military in 1925 with the rank of major.

Arnot lived quietly after his retirement from Babcock and Wilcox. He moved to Castle Hill in New South Wales, where he died on October 15, 1946.

THE ELECTRIC DRILL

Following the development of practical electric motors in the 1870's and 1880's, inventors and engineers rushed to find ways to put the motors to use. Electricity promised to make cumbersome tasks easier, and by the end of the nineteenth century electric motors were powering fans, carpet sweepers, vehicles, and industrial machinery. Because an electric motor converts electrical energy to mechanical energy, it could perform repetitive, laborious work such as drilling into rock.

Drills have been used by humans for thousands of years, dating back to the ancient Egyptian and Harappan civilizations (in present-day India and Pakistan). The earliest drills were bow drills, consisting of two sticks and a length of cord. By making a simple bow from one stick and the cord, and wrapping that cord around the other stick, the operator could rotate the second stick back and forth quickly. This tool could be used to make holes in soft materials or to ignite fires. Centuries of development led to larger machines and harder bits, but drilling—especially in rock—still took a great deal of time and labor. In the middle of the nineteenth century, drilling underground was done by hitting a steel rod with a sledgehammer. Simon Ingersoll invented a percussion drill that both pounded and rotated the steel rod, making it move forward quickly, and in 1870 he invented the steam-powered drill. The new drill was a great advancement, but the steam made it dangerous to operate. When Arthur James Arnot married the drill and the electric motor in 1889, he solved one of the great challenges facing an industrial world hungry for coal to power new machines.

The potential uses for the electric drill were immediately apparent, and other engineers rushed to make improvements. In 1895, six years after Arnot's drill was patented, brothers Wilhelm and Carl Fein of Stuttgart, Germany, took out a patent on a drill that could be held in the hand. They continued to work on ways to make the drill more portable, eventually making some components from aluminum to reduce the weight. In 1917, a young American company called Black and Decker patented a pistol grip and trigger switch for a handheld electric drill, and the success of its drill enabled the company to grow into a large international conglomerate. In 1929, Black and Decker opened a subsidiary in Sydney, and by 1946, the year of Arnot's death, the company was one of the largest industrial firms in Australia, producing power tools for home and industrial uses. There is no record of how Arnot responded to the tremendous success of the electric drill he had invented.

IMPACT

As an engineer, Arnot played an important role in the electrification of Australia. It is one thing to power a light bulb in a laboratory, and quite another to light an entire city. Arnot's design for the Spencer Street Power Station put Melbourne on the electrical map, and Arnot successfully managed the plant for more than a decade in which understanding of electricity and of electrical engineering grew at a rapid pace. The story of the early years of the power station includes controversies over the new field of electrification: the uses of AC and DC power, the struggles between municipal and private companies, the movement toward the standardization of amperes transmitted, and the rush to obtain coal for steam generation.

Arnot left his mark as an inventor. His need for a large and steady supply of coal for his Spencer Street Power Station led him and his colleagues Brain and Baker to use one of the new electric motors to power a drill to dig through rock more quickly than other methods. They could not have foreseen that this large industrial machine would become a common tool within forty years. From the tiny drills used in dentistry, to small handheld drills in the toolboxes of carpenters and homeowners, to large electric rock drills used in mining, the electric drill has played an important role in making work easier in the age of technology.

—Cynthia A. Bily

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See also: Thomas Alva Edison; William Sturgeon.

JOHN VINCENT ATANASOFF

American mathematician and physicist

Atanasoff played a key role in the development of the electronic computer. He contributed to the computer revolution by proving that electronic computation was feasible and by incorporating some of the features basic to modern computers.

Born: October 4, 1903; Hamilton, New York
Died: June 15, 1995; Monrovia, Maryland
Also known as: Dzhon Vinsent Atanasov (birth name)
Primary fields: Computer science; mathematics; physics
Primary invention: Atanasoff-Berry Computer

EARLY LIFE

John Vincent Atanasoff (uh-ta-NUH-sahf) was born in Hamilton, New York, in 1903, to Iva Purdy and Ivan Atanasov, an electrical engineer. When his father had immigrated to the United States from Bulgaria, immigration officials changed his name to John Atanasoff. The family moved to central Florida when John Vincent was eight. He was the oldest of nine children.

Both John's father and mother encouraged him when his mathematical talents appeared. His father gave him a slide rule when he was about nine years old and showed him how to use it. Between the instruction book for the slide rule and a college algebra textbook, Atanasoff learned how to use the slide rule to perform complicated mathematics, including logarithms. His mother gave him a book that discussed number systems in different bases.

By the time Atanasoff reached high school, he knew that he wanted to be a theoretical physicist. However, the University of Florida did not offer a degree in that field, so he majored in electrical engineering. He graduated in 1925 and went on to earn a master's degree from Iowa State College (now Iowa State University) in 1926. The University of Wisconsin awarded him a Ph.D. in theoretical physics in 1930. Atanasoff returned to Iowa State with a faculty appointment in the Mathematics and later the Physics departments.

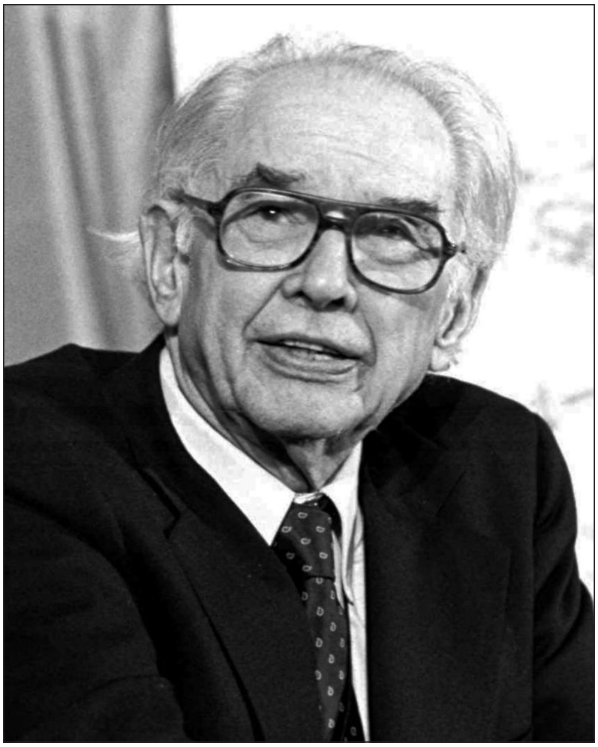
Life's Work

As a theoretical physicist, Atanasoff had to find solutions to large and complex sets of equations by hand. The main problem that Atanasoff was trying to solve was a system of linear equations. He estimated that it would take a human 125 hours to solve twenty equations in twenty unknowns. He decided to try calculators to speed up the process. His goal was a machine that could solve a system of thirty equations in thirty unknowns. He tried modifying an IBM tabulator or connecting several calculators together. However, mechanical machines proved cumbersome and limited the complexity of the problems they could solve. As the complexity of the machine grew, so did its size and the heat it produced. In addition, mechanical parts moving rapidly against one another caused wear and tear and required lots of maintenance.

One day in the winter of 1937, a frustrated Atanasoff went for a drive that would prove historic. A lover of whiskey and fast cars, he drove two hundred miles to cross the Illinois border (Iowa was still constrained by Prohibition), where he found a tavern and had a few drinks. He realized that he could design a device to store the coefficients of his equations. In addition, electronic components could more easily and accurately handle digital rather than analog data. Binary numbers were a natural "on-off" (charged-discharged) system for an electronic computer. By the time he left, he had written notes on the back of a napkin that outlined principles for an electronic computer. It included the use of base-2 (binary) numbers rather than the traditional base-10 (decimal), direct 0-1 logic rather than enumeration, and a separate memory with capacitors that would be "refreshed" to prevent the loss of data.

Back at Iowa State, Atanasoff decided to use logic circuits rather than simply mimicking the action of mechanical calculators. His machine would be the first to calculate with vacuum tubes and do arithmetic electronically. In 1939, with a grant from Iowa State, he hired graduate student Clifford Berry to assist him. Berry's skill in electronics complemented Atanasoff's skills in math and physics. By the fall of 1939, the team had built a crude, small prototype that could add and subtract.

In 1940, Atanasoff attended a lecture on computing by John William Mauchly. Atanasoff approached him, and they began to correspond. Mauchly visited Iowa in June, 1941. Atanasoff showed Mauchly the various parts of the machine that he and Berry were constructing and explained their functions. Atanasoff also showed Mauchly a proposal he had written, which was essentially a systematic blueprint for the construction of an electronic computer. It included details on the use of binary numbers, 0-1 logic, vacuum tubes, and capacitors for memory. Atanasoff's work influenced Mauchly's ideas when he and John Presper Eckert built the Electronic Numerical Integrator and Computer (ENIAC), the first general-purpose electronic computer.



John Vincent Atanasoff. (AP/Wide World Photos)

Atanasoff's proposal had been a grant request to the Iowa State College Research Corporation. In 1941, the corporation awarded the grant, and the college appointed a lawyer to patent the machine. Atanasoff negotiated a 50/50 split on any royalties. He also agreed that part of his half was to go to Berry, an unusual acknowledgment of a graduate student's contribution. While Atanasoff was responsible for the concept and ideas, Berry was responsible for most of the detailed design and construction. However, the attorney and the college never applied for the patent.

In 1942, Atanasoff and Berry had produced a working electronic special-purpose computer. What later became known as the Atanasoff-Berry Computer (ABC) employed various new techniques that Atanasoff had invented, including novel uses of logic circuitry and regenerative memory. However, the part of the machine that was to record intermediate results on paper did not fully work for large systems of equations, only small ones up to five equations and five unknowns.

The United States' entry into World War II ended Atanasoff and Berry's work, as they both left Iowa for jobs in the defense industry. Atanasoff went to work for the Naval Ordnance Laboratory in Maryland and focused on acoustics and seismology. The Atanasoff-Berry Computer remained in the basement of the physics building where they had built it. Atanasoff thought he would return to the work after the war; however, he declined Iowa State's offer to return and head the Physics Department. A new chair of the department needed the space in the basement and disassembled the ABC in 1948.

The U.S. Navy awarded Atanasoff the Distinguished Service Award in 1945 for his work with the Naval Ordnance Laboratory during World War II. Atanasoff worked for the Ordnance Lab through 1952, when he founded the Ordnance Engineering Corporation. He also served as president of Cybernetics, Inc., from 1961 to 1980. Although Atanasoff never received a patent for the ABC, he did hold patents for thirty-two other inventions.

In 1973, a federal court decision named John Vincent Atanasoff as the inventor of the first electronic computer. Sperry Rand had acquired rights to the ENIAC patents, and some computer manufacturers still paid royalties to Sperry Rand for some of the principles derived from the ENIAC. Honeywell no longer wanted to pay the royalties and challenged Sperry Rand based on Atanasoff's work. The case went to court in 1971. Judge Earl R. Larson of the Minneapolis Federal Court ruled that "the subject matter of one or more claims of the ENIAC was derived from Atanasoff, and the invention claimed in the ENIAC was derived from Atanasoff."

Atanasoff's work influenced developments during the next decade and the rapid development of electronic computers. His ABC was the first in a chain of machines that far outstripped their predecessors. He retired to his farm near Monrovia, Maryland, where he died on June 15, 1995, of a stroke.

THE ATANASOFF-BERRY COMPUTER

The Atanasoff-Berry Computer (ABC) was the size of a large desk or chest freezer and probably weighed almost seven hundred pounds. All the parts were mounted on a metal frame. There was an operator's control console on top with numerous switches, buttons, meters, and lights. Underneath the console was the arithmetic unit (performed addition and subtraction), which contained more than two hundred vacuum tubes. Beside it was a card reader and puncher for input and output. Two rotating drums served as the memory and sat behind the card equipment. Each drum had sixteen hundred capacitors set into its skin in thirty-two rows. Each drum stored thirty fifty-bit numbers (fifteen-place decimal numbers).

In the binary (base-2) system, there are only 1's and 0's (unlike the decimal system that has 0's, 1's, 2's, 3's, 4's, 5's, 6's, 7's, 8's, and 9's). Capacitors would represent a digit by being charged positively (1) or negatively (0). Since the capacitors drained their charge about the time a drum made one complete revolution, John Vincent Atanasoff designed a circuit to regenerate the charge on each rotation. While crude, this is the basis of the modern dynamic RAM in every computer.

Atanasoff designed the ABC to solve systems of linear equations. For example, a system of two equations and two unknowns could be: $2a + 11b = 30$; $4a + 6b = 28$. (The answer can be worked out by hand to $a = 4$ and $b = 2$.) Atanasoff wanted to be able to solve up to thirty equations and thirty unknowns.

The part of the machine that prevented it from working for large systems was the card puncher. Solving systems of linear equations required saving intermediate results. If the machine saved these by mechanically punching cards and then reading them back in, the process would take far too long. Atanasoff devised a way to create the holes electrically rather than mechanically. It was faster, but it failed once every 100,000 times. While this may seem like a minor problem, large systems of equations required hundreds of thousands of operations. Thus, the error would occur and produce incorrect results.

IMPACT

Atanasoff played a key and controversial role in the development of the electronic computer. His machine only worked for small systems of linear equations because error crept in with larger systems. However, his work influenced John William Mauchly, one of the designers of the first general-purpose electronic computer, the ENIAC. The ENIAC led to stored-program computers like the Electronic Discrete Variable Automatic Computer (EDVAC).

Particular components of the ABC were innovative and became basic elements in computers. The machine pioneered a regenerative memory. It used regenerative pulses to stop the charges in the capacitors from "leaking" away. This technique is still the basis of modern dynamic random access memory (RAM). Other innovations included the use of vacuum tubes, the use of binary numbers, and the use of electronic logic rather than simple enumerations.

A surprising number of things have not changed since the invention of the ABC. Supercomputers were optimized for matrix factoring and matrix multiplication—essentially the same problem as solving systems of linear equations. An Intel press release on its parallel processor (which had demonstrated over a trillion operations per second) indicated that the problem the processor solved was a linear system of 125,000 equations in 125,000 unknowns.

—Linda Eikmeier Endersby

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Hally, Mike. *Electronic Brains: Stories from the Dawn of the Computer Age*. Washington, D.C.: J. Henry Press, 2005. Readable book with details of various machines and personalities significant in the development of the modern computer. Includes one chapter with information on Atanasoff's work. Useful appendixes explain technical terms, binary mathematics, and parts of the modern computer. Illustrations, references, index.

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See also: Clifford Berry; Seymour Cray; John William Mauchly.

HERTHA MARKS AYRTON

English engineer and mathematician

Ayrton made improvements to the electric arc, an important illumination source in the nineteenth century. She also invented a drafting tool and a manually operated fan.

Born: April 28, 1854; Portsea, England
Died: August 26, 1923; North Lancing, Sussex, England
Also known as: Phoebe Sarah Marks (birth name)
Primary field: Electronics and electrical engineering
Primary inventions: Carbon electric arc; Ayrton fan

EARLY LIFE

Phoebe Sarah Marks was the third of eight children of Levi and Alice Theresa (Moss) Marks. Anti-Semitism had induced Levi to emigrate from his native Poland. He struggled to support his large family as a clockmaker and jeweler. In 1861, Levi died, leaving his family with debts. Alice, who was known for her civic and charitable activities, supported her children by selling needlework.

Sarah gained both mechanical talent and a compassionate concern for others from her parents. When she was nine years old, Sarah went to live with her maternal aunt in London, where she received her early education. Her cousin, a graduate of Cambridge University, taught mathematics to Sarah and introduced her to writers and other intellectuals. As a teenager, Sarah decided to leave the Jewish religion, though she remained proud of her heritage. The young agnostic took the name Hertha, the name of a Germanic earth goddess featured in a popular poem by Algernon Charles Swinburne.

Hertha Marks tutored students and sold embroidery to earn money, much of which she sent to her family. One of the founders of Girton College at Cambridge University, Barbara Leigh Smith Bodichon, offered to subsidize Marks's education. Marks passed entrance examinations in mathematics and English with honors and entered the college in 1876. While she was a student, Marks invented an instrument for recording pulse beats, but after learning that others had preceded her, she did not continue working on it. She completed the Cambridge Tripos examinations in 1881. Since Cambridge did not grant degrees to women, Marks was not eligible.

After inventing a drafting tool that was well received, Marks realized that she might be able to pursue a scientific career. With financial support from Madame Bodichon, she began studying in 1884 at Finsbury Technical College in London under William Ayrton, professor of physics and prominent electrical engineer. Marks and Ayrton married the next year. They had one daughter, Barbara.

LIFE'S WORK

Hertha Ayrton's first invention was a device for dividing a line into equal parts. Her design was based on the principle that corresponding sides in similar triangles are proportional, and was somewhat related to the drawing compass. Marks patented this invention in 1884 and engaged a British manufacturer.

After marrying Professor Ayrton in 1885, she became involved with his investigations of the electric arc. At that time, arc lamps were an important source of illumination for streets, factories, stores, and other public places. Their intense, harsh light made them best suited for commercial purposes. The electric arc was also used for searchlights. Unfortunately, arc lamps were also noisy, producing unpleasant hissing, humming, and sputtering, and they rotated spontaneously, which changed the color and intensity of light. Arc lamps were temperamental and required many adjustments to keep them operating. During use, the arc's high temperatures vaporized the carbon electrodes and melted most insulation materials. As the electrodes deteriorated, the distance between them changed, making corrections to the circuit and to positions of searchlight mirrors necessary.

The basic arc lamp consisted of two electrodes housed in a receptacle. When a high-voltage source was connected to the electrodes, molecules of the ambient air would break down into charged particles, or ions. A surge of current (discharge) resulted as the ions suddenly moved to the electrodes. The energy transmitted by these rapidly moving particles would heat the electrodes to incandescence. The electrodes were usually made of carbon, although other materials could be substituted.

The relationship of variables in the arc circuit were not well understood at that time, and Hertha Ayrton realized that this relationship was key to improving the arc. While experimenting with the arc circuit, she found that, for a constant current, the power required was directly proportional to the length of the arc. The current and electric potential were inversely proportional. Ayrton then turned to the question of the electrodes themselves. During the arc's operation, depressions (craters) developed in the tips of the electrodes as the carbon dissipated. She found that variations in these craters affected the potential needed to maintain the arc discharge.

Next, Ayrton attacked the vexing problem of the hissing arc. Besides being annoying, hissing arcs were not stable. Ayrton found that when a carbon electrode oxidized instead of vaporizing, the crater would spread from the tip to the sides. This change in shape left a path for air to rush in, turn the electrode, and make the unwanted hissing sound. Ayrton realized that manufacturers were creating the conditions required for a hissing arc by placing grooves along the sides of the electrodes. She also recognized that electrodes with flat ends would better resist degradation than the tapered carbons being marketed.

Ayrton's analysis and solution for the hissing arc quickly brought professional recognition. This achievement transformed Ayrton's public image from helpmate to established independent researcher. The Institution of Electrical Engineers broke tradition and permitted Ayrton to read her own paper in 1899 rather than requiring a man to present it. The institution awarded her a prize of £10 and made her its first female member.

After this feat, Ayrton was invited to participate in other meetings and conferences. She compiled her researches into a book on the electric arc that was published in 1902. The British Admiralty consulted with Ayrton on methods to improve carbons in searchlights. She also designed improvements for movie projectors. Ayrton patented many of her inventions.

In 1901, Ayrton noticed sand ripple patterns formed by ocean waves at the beach. Her curiosity led her to investigate water vortices and waves, resulting in several publications. She devised a pressure-difference gauge to confirm her analysis. In 1906, the Royal Society of London awarded Ayrton the prestigious Hughes Medal for her work on the electric arc and on sand ripples. Unlike the Institution of Electrical Engineers, the Royal Society did not grant her membership, deciding instead that a married woman was not eligible.

During World War I, dismayed by the deaths and suffering unleashed by poisonous gas warfare, Ayrton transferred her knowledge of sand ripples and hydrodynamics to the behavior of air. Soon she had invented a fan to move toxic gases out of the trenches, which she offered free of charge and hoped would save many lives. A frustrating combination of indifference and bureaucratic bungling prevented the fan's timely deployment, a source of deep pain to Ayrton. In 1917, she devised a mechanical version of her fan but apparently did not pursue this. Ayrton died in North Lancing, Sussex, on August 26, 1923.

IMPACT

Ayrton's work was part of an engineering tradition that attacked concrete physical problems without using abstract models or theories. Her work on the electric arc was significant for the electric lighting industry. Though electric arcs became less important for lighting after the invention of the incandescent lamp, they continued to be used in searchlights, in projectors, and for welding. Because arcs produce high temperatures, they were used in furnaces to make steel.

The electric arc was especially interesting for physical theory, as scientists recognized that the arc discharge took place in a special state of matter, an assemblage of ions. Investigations of electrical discharges in ionized gases occupied many physicists during the late nineteenth century. Now called plasma physics, the study of ionized gases has applications in physics, astrophysics, and meteorology.

Ayrton's line divider was patented and marketed for engineers, architects, artists, and other professionals, and her fan for removing toxic gases from trenches proved useful during World War I. However, Ayrton may be best remembered for her personal achievement in rising beyond her economically straitened origins and excelling in a field dominated by men. Ayrton struggled against economic, social, and cultural barriers to pursue her career. Her life is both an inspiration for young people and a case study for exceptional women. As with many women of her era, Ayrton's path was smoothed by an influential man. Like most successful scientists and engineers of either gender, she had supportive mentors and gained the necessary financial means to pursue her goals. Ayrton was also aided by her enthusiasm, charm, and sociability. She was a trailblazer, making way for other women to pursue careers in engineering and science.

—*Marjorie C. Malley*

THE AYRTON FAN

The hand-operated fan Hertha Marks Ayrton developed for the British army was made of waterproof canvas and cane, with a wooden handle. Its fifteen-inch square blade had a firm center with side and end flaps. These loose flaps prevented fumes from rushing into the area behind the fan, ensuring they would be dispelled. Made to be portable, it was three and a half feet long, weighed less than one pound, and could be folded.

The fan worked by creating disturbances in the air that traveled toward the fumes. As the fan beat in a regular rhythm, this wave pattern could be reinforced, creating standing waves that caused the air to rise higher and higher. The up-and-down motion of the fan also produced a vortex in the air. Ayrton designed her fan so that the air vortices moved only in the forward direction. Successive beats of the fan created a series of vortices that combined their energy into a huge vortex that carried away the poisonous gases.

The Ayrton fan produced a partial vacuum in the region behind it that drew fresh air toward the fan at the same time as the rotational motion of the air in front of the fan moved air away from the device. With a small experimental model, Ayrton could clear a large smoke cloud in a few seconds, moving the air out to ten feet. The army fan could clear a much larger volume of fumes. British forces used the Ayrton fan during World War I for moving noxious gases from exploding shells out of trenches, mine craters, and other depressions.

FURTHER READING

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Bowers, Brian. *Lengthening the Day: A History of Lighting Technology*. New York: Oxford University Press, 1998. Informative book by the science curator of London's Science Museum that traces lighting from antiquity to modern times. Includes a chapter on the electric arc. Illustrations, bibliographical references, index.

Malley, Marjorie. "Hertha Marks Ayrton." In *Women in Chemistry and Physics*, edited by Louise S. Grinstein, Rose K. Rose, and Miriam H. Rafailovich. Westport, Conn.: Greenwood Press, 1993. Based on original publications, this essay relates and interprets major aspects of Ayrton's life and work. Part of a collection featuring many lesser-known scientists. Notes, bibliography.

Mason, Joan. "Hertha Ayrton (1854-1923)." In *Out of the Shadows: Contributions of Twentieth Century Women to Physics*, edited by Nina Byers and Gary Williams. New York: Cambridge University Press, 2006. Engaging sketch of Ayrton that includes several of her extrascientific activities, as well as an overview of her scientific work. Notes, portrait, bibliography.

Sharp, Evelyn. *Hertha Ayrton, 1854-1923*. London: Edward Arnold, 1926. Written by a friend, the only full length biography of Ayrton paints a portrait of a warm, spirited, resourceful woman of broad interests and endeavors. Illustrations.

See also: Meredith C. Gourdine; Peter Cooper Hewitt.

CHARLES BABBAGE

English mathematician and mechanical engineer

Babbage was the originator and cocreator (with his close friend Ada Lovelace) of the programmable computer. His primary invention, the difference engine, could calculate polynomials far faster and more accurately than previously possible.

Born: December 26, 1791; in or near London, England
Died: October 18, 1871; London, England
Primary fields: Computer science; mathematics
Primary invention: Difference engine

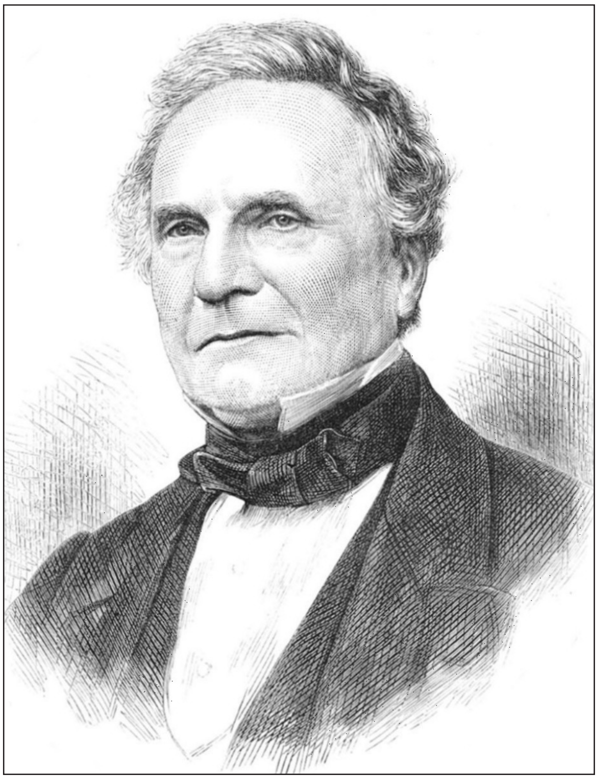
EARLY LIFE

Charles Babbage was one of four children born to Benjamin Babbage, a banker, and Betsy Plumleigh Teape. His birthplace is uncertain, but a memorial plaque at the intersection of Walworth Road and Larcom Street states that he was most likely born in the house at 44 Crosby Row, Walworth Road, in London, England. In 1808, Babbage's father moved the family to East Teignmouth, where he accepted a position as a warden of St. Michael's Church. Finding himself sufficiently supplied with money to pay for his son's private-school education, Benjamin sent Charles to a school in Alphington. Since he had recently recovered from fever, the boy was told not to study too hard. Later, Charles enrolled at King Edward VI Grammar School in Totnes, but, again, his health prevented him from making significant progress in his studies. Holmwood Academy, a school founded by the Reverend Stephen Freeman, was the real beginning of Babbage's education. Its library, well stocked with mathematical treatises, was inspiring. Babbage was accepted into Cambridge University in 1810.

When Babbage arrived at Trinity College, Cambridge, in October of that year, he had had significant exposure to such luminaries as Gottfried Wilhelm Leibniz, Joseph-Louis Lagrange, and Sylvestre François Lacroix. Consequently, he found that his chosen school had little else to teach him in the field of mathematics. With some of his college friends, Babbage created an Analytical Society in 1812 composed of a handful of Cambridge undergraduates: Babbage, George Peacock, John Herschel, Michael Faraday, Isambard Kingdom Brunel (a future railway pioneer and mentor for Charles's son Benjamin Herschel Babbage), and Edward Ryan. Ryan and Babbage married, respectively, Louisa and Georgiana Whitmore, the sisters of Wolryche Whitmore, a founder of South Australia and the member of Parliament who helped repeal the infamous Corn Laws. In hopes of finding a better education, Babbage transferred to Peterhouse, Cambridge, in 1812. Although he became Peterhouse's highest-ranked mathematician, he failed to graduate. In 1814, he received an honorary master's degree without examination and became a professor of mathematics.

LIFE'S WORK

Babbage and his beloved Georgiana were married on July 25, 1814, at St. Michael's Church and settled down to life at 5 Devonshire Street in London. Babbage's primary occupation at the time was studying the calculus of functions. In 1816, his mathematical prowess earned him a fellowship in the Royal Society and encouraged him to found the Astronomical Society (later the Royal Astronomical Society). By 1820, however, he had become fascinated by the idea of a mechanical calculator and began working on a machine that could calculate mathematical tables quickly and accurately. At the time, all calculations were performed by human "computers," whose function was to compute the value of numbers. Babbage disliked the inac-



Charles Babbage. (Library of Congress) curacy of human computers and was inspired to study logarithmic tables and to refine earlier calculating machines invented by Blaise Pascal and Leibniz. In 1822, having hit upon what he felt was a workable design, Babbage wrote Sir Humphry Davy, the president of the Royal Society, a letter outlining his proposed mechanism and requesting funding. Finding approval from the Chancellor of the Exchequer, Babbage was able to start constructing the "difference engine" in 1823. Created specifically to compute the values of polynomial functions, the difference engine eliminated the need for multiplication and division in the fields of accounting and mathematics. Further, the automatic nature of the difference engine meant that a user did not need to be mathematically gifted to operate it.

Because Babbage was unable to secure sufficient funding for his devices, none of his inventions were ever completely constructed. The first version of the difference engine, weighing fifteen tons and composed of more than twenty-five thousand individual moving parts, was a monstrosity that defied completion. Eventually, in 1991, a fully working model of Babbage's machine was made based on his original blueprints, but throughout the inventor's life he only managed to build sections of his machines.

Despondent, but not defeated, Babbage continued his refinement of the calculator. The next incarnation of the difference engine, called the analytical engine, was more complex and even included a printer that could record its calculations on paper. Further, Babbage's friend, Ada Lovelace, designed a program for the analytical engine on a series of punch cards to control its functions, including looping, branching, and sequential control—functions present in modern computers. Additional designs for Babbage's difference engine, limited to theoretical sketches and mechanical designs, further modified the original functions of the difference engine. When it was finally constructed in 1991, the mechanical calculator was found to be able to calculate accurately to thirty-one digits.

Sadly, Georgiana passed away at the age of thirty-five on September 1, 1827, the same year that Babbage's father died. Additionally, of the couples' eight children, only two sons (Benjamin Herschel and Henry Prevost) and one daughter (Georgiana) survived childhood. The failure to finish building his engine, and the death of his father, wife, and one son in the same year, caused Babbage such grief that he delayed construction of the device.

Fortunately, Babbage was able to rely on the support of Ada Lovelace, whom he met in 1833. An impressive mathematician in her own right and considered by many later scholars as the "mother of programming," Lovelace had gone into the field of mathematics with the intent of obscuring the notoriety of her father, the poet Lord Byron. The program she devised for the analytical engine would have calculated Bernoulli numbers had it ever been run on the finished engine.

Babbage died of unspecified causes on October 18, 1871, at the age of seventy-nine, having never seen the completion of a single project. He was buried in London's Kensal Green Cemetery. His son Henry assembled part of Babbage's difference engine from recovered parts but also found the engine to be too daunting a task. Babbage's various engines, unwieldy and erratic, nevertheless share a structure with the modern computer.

THE DIFFERENCE ENGINE

The difference engine, a mechanical calculator based on Sir Isaac Newton's method of divided differences and designed to tabulate polynomial functions, consisted of columns (1 to n) that each stored one decimal number. A crank on the side of the engine caused the gears to move and add the value of column n + 1 to column n to produce the new value of column n. Further, column n could store only a constant, while column 1 displayed the value of the calculation. Despite this limited ability, both logarithmic and trigonometric functions could be calculated through the use of polynomials and, consequently, added more functions to even the limited nature of the original difference engine. Before its execution, the mechanism had to be programmed, with initial values set to the columns.

When Charles Babbage wrote a paper for the Royal Astronomical Society proposing the design and construction of a calculating machine, the government was impressed enough with the idea to award him limited funding in 1823. The failure of the original project, however, caused the withdrawal of support even though Babbage greatly improved the design of the original engine in his plans for his analytical engine and its successive versions. Babbage requested funding several times, but the lack of observable progress made his patron leery of investing in his designs. It was only the intense curiosity of curators at London's Science Museum and Babbage scholars that led to the construction and testing of Babbage's designs for the difference engine and the analytical engine. Although Babbage did not live to see the vindication of his theories, his faith in the promise of his calculators inspired many generations of later mathematicians to perfect his mechanisms.

IMPACT

It is difficult to judge the impact of Babbage's engines because not a single machine was ever completely constructed. Further, the few trials of the first incomplete difference engine were riddled with errors. The theoretical designs inspired the development of computers and computer programming, but scholars continue to debate whether Babbage's machines would have worked had he finished them while he was still alive. The Science Museum in London attempted to answer the debate by constructing two full-scale replicas between 1989 and 1991. Both are on display, one at the Science Museum and the other, owned by Nathan Myhrvold, on exhibit at the Computer History Museum in Mountain View, California. Interestingly, both replicas work astoundingly well, given the failure of their ancestors. The replica of Babbage's Difference Engine No. 2 (produced between 1847 and 1849) could hold seven numbers of thirty-one decimal digits each and thus could accurately calculate seventh-degree polynomials, more than many modern calculators.

Perhaps Babbage's greatest impact was his desire to replace human computers with accurate machines. Computing work, even with the aid of an abacus, was a hard and unrewarding job for the people assigned to add and subtract numbers. Accounting, consequently, tended to be drudgery, and a high rate of error was common. The modern era's reliance on accurate data is a direct result of Babbage's insistence on mechanical calculation.

—*Julia M. Meyers*

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Babbage, Charles. *Passages from the Life of a Philosopher*. Silver Springs, Md.: Merchant Books, 2008. A reprint of a memoir by Babbage that relates many details of his life unrelated to his inventions. Very rare unabridged and digitally enlarged printing of Babbage's autobiography.

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Halacy, Dan. *Charles Babbage: Father of the Computer*. New York: Macmillan, 1970. A biographical account of Babbage and his invention of the difference engine that touches on the evolving nature of Babbage's computational theory. Discusses the implications of the difference engines for the development of the modern computer.

Hyman, Anthony. *Memoir of the Life and Labours of the Late Charles Babbage, Esq., F.R.S.* Cambridge, Mass.: MIT Press, 1988. Unpublished during Babbage's lifetime, this memoir by a contemporary is very useful for information about Babbage's personal habits and dedication to his work.

Swade, Doron. *The Difference Engine*. New York: Viking Press, 2001. As the leader of the team that built a replica of Babbage's difference engine on the occasion of the two hundredth anniversary of Babbage's birth, Swade is highly qualified to discuss Babbage's inventions. His book, describing Babbage's work in Kensington, is a fascinating tribute to the "father of computing."

See also: John Vincent Atanasoff; Clifford Berry; William Seward Burroughs; Seymour Cray; Sir Humphry Davy; John Presper Eckert; Ted Hoff; Herman Hollerith; Jack St. Clair Kilby; Gottfried Wilhelm Leibniz; John William Mauchly; John Napier; Sir Isaac Newton; Blaise Pascal; Alan Mathison Turing; Konrad Zuse.

ROGER BACON

English scientist

Bacon was one of the first Europeans to formulate the scientific method. Based on experiment, not accepted authority, his work depended upon observation. His work with optics was seminal, and he anticipated modern science by integrating logic and quantitative reasoning.

Born: c. 1220; Ilchester, Somerset, England
Died: c. 1292; Probably Oxford, England
Also known as: Doctor Mirabilis
Primary fields: Chemistry; mathematics; optics; physics
Primary inventions: Empiricism; experimentation with lenses and prisms

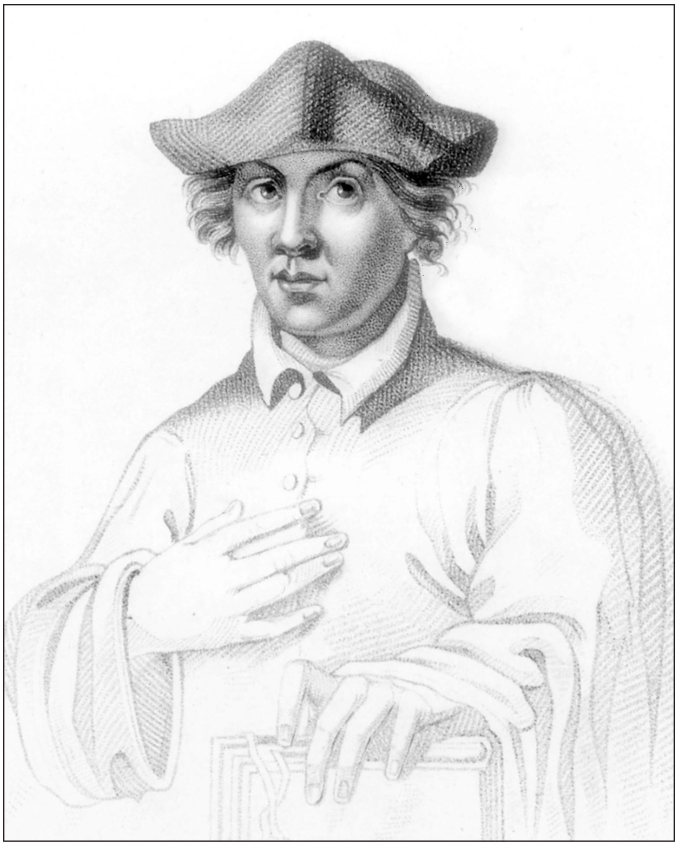
EARLY LIFE

Roger Bacon was born to wealthy parents in a family that valued education. One of several children, at least one of his older brothers also received an early education by a Latin tutor just as Roger did. His landowner parents, who were probably titled nobility, expected Roger to enter the Church and follow the normal route for a younger son who would not inherit the title or a majority of land as the eldest son would. This medieval system was known as primogeniture, from the Latin for "eldest-born [son]," and is still followed today to some extent in European titled families. Whether he attended some form of grammar school or was privately taught, he would have first studied Latin and basic arithmetic or computation.

While there is some debate about his exact year of birth (also possibly later in 1222), at the age of thirteen Roger Bacon entered Oxford University, where instruction was almost entirely in Latin and which at the time compressed secondary or high school and college together. At Oxford, Bacon would have built upon his early schooling with grammar, logic, and rhetoric in Latin and followed this with music, astronomy, arithmetic, and geometry. Bacon first earned his bachelor of arts degree by his late adolescence and his master of arts degree by his early twenties. It was at Oxford where Bacon was exposed to two subjects that would become lifetime influences, Aristotle and logic, and where his love of thinking honed through his studies would have naturally led him to methodical scientific observation and to reject any knowledge or philosophy based only on authority and not on what could be tested by experimental reasoning.

LIFE'S WORK

Bacon taught Aristotle at Oxford for at least a decade until around 1241. Study of Aristotle had fallen out of favor with the Church for a long time because he was considered a pagan philosopher, but Aristotle had been reinstated as worthy of study during and shortly after Bacon's time at Oxford and Paris. In 1241, Bacon moved to Paris and taught Aristotle at the University of Paris. This was the period when he began a visibly serious interest in science, possibly influenced by several contemporary medieval philosopher-scientists like the French scholar Petrus Peregrinus de Maricourt (mostly in the thirteenth century) and Robert Grosseteste of Lincoln (1175-1253).



Depiction of Roger Bacon patterned on a print by Flemish painter Aegidius Sadeler. (Library of Congress)

Petrus Peregrinus studied mathematics and magnetism and also described the principles and construction of an astrolabe. Robert Grosseteste wrote on astronomy, light, and tides and also made commentaries on Aristotle. It is likely that Bacon began studying Grosseteste while in his first Oxford period.

This is also the time when Bacon began his linguistic forays into other languages and cultures, as Paris and the Continent had far more manuscripts available to him than Oxford. Part of this manuscript access to oriental thought was due to the earlier Carolingian Renaissance of Charlemagne, but more so to the worldly influence of the Crusades, where new exposure was coupled with the intellectual legacy of individual kings like Frederick II (1194-1250), who was also leader of the Holy Roman Empire in Germany and welcomed Arab and Jewish scholars, as well as proximity of the Moors in nearby Spain.

Bacon heavily criticized the Scholastic biblical studies of his own day, noting their reliance on bad translations and faulty commentaries that showed ignorance of the original texts. He emphasized that the Scriptures were more important than the commentaries derived from them. In this sense, he anticipated the Reformation.

During his Paris years, regretting his own reliance on Latin translation, Bacon studied earlier scientists, notably the Arabic mathematicians and scientists such as Ibn al-Haytham (c. 965-1039), also known as Alhazen, and the much earlier polymath al-Kindī (c. 801-873), also known in Latin as Alkindus. Al-Haytham is often called the "father of optics" for his work on prisms, lens making, mirrors, reflection, magnifying glasses, and other visual phenomena described in his *Kitāb al-manāzir* (wr. 1011-1021; book of optics). Al-Kindi had been one of the pioneers in introducing numerals from India that formed the basis of Arabic numerals that ultimately liberated numeracy in the West from the cumbersome Latin number system. Al-Kindi also theorized on cryptography and frequency analysis, applying logic to codes. This was a revolutionary period in Bacon's life. After six years in Paris, Bacon may have returned to Oxford and in 1247 begun experiments that would be the hallmark of his life from then on, possibly performing hundreds of experiments in optics and applying geometry to optics.

It was thus that Bacon became the "father of empiricism." Understanding that he could only believe scientifically what could be verified repeatedly through experiment and the senses, Bacon's experiments carefully assembled the empirical method of science, starting with hypothesis, testable by experiment and laying out the influencing variables and permutations before arriving at any conclusions. Based on his own experiments with optics and lens making, he may have been one of the inventors of the telescope. In his own words he wrote:

> For we can so shape transparent bodies, and arrange them in such a way with respect to our sight and objects of vision, that the rays will be reflected and bent in any direction we desire, and under any angle we wish, we may see the object near or at a distance. . . . So we might also cause the Sun, Moon and stars in appearance to descend here below. . . .

The ability to draw the celestial bodies closer in—"Sun, Moon and Stars in appearance to descend here below"—seems impossible to achieve without the magnification power of a series of separate lenses of a telescope. Bacon also believed that Earth was a sphere, a deduction derivable by geometric principles, and that enough water existed in oceans to circumnavigate the planet. Also using geometry, he deduced the nearest stars were over 130 million miles distant, greatly in error considering the Earth-Sun distance is around 93 million miles, but nonetheless a huge sum for his day.

Bacon also wrote on prisms, correctly described the visible spectrum he could observe in light passing through water, and appears to have been the first in the West to have correctly experimentally determined the maximum reflective altitude of a rainbow as comprising 42° of arc at its greatest intensity. Using simple astronomy, he also proposed to the Church a logical overhaul of the Julian calendar, a proposal that was basically ignored for centuries. In his writing on chemistry, Bacon was the first to describe the making of gunpowder and firecrackers using saltpeter and sulfur, several decades before Marco Polo returned from China around 1299. Bacon's most important intellectual credo can be found in his own words, "Mathematics is the gate and key to the sciences."

At some point, Bacon had become a Franciscan friar, possibly to finance his experiments and writing because this order often harbored many thinkers and possibly because his once-wealthy family was now in poverty, penalized for having supported the wrong side in an English civil war. Because of his monastic vows, Bacon was also intermittently under intense scrutiny and possible persecution—or at least censure—for his beliefs and scientific thought when it clashed with perceived theology and doctrine. Although many early scientists often under the aegis of the Church practiced what was under-

FORESIGHT WITH LENSES

Roger Bacon has been often credited with several inventions, including the telescope and working spectacles, although these are much debated. He was, however, one of the first Europeans to theorize about both of these inventions—certainly as early as 1234 in regard to telescopic lenses and 1268 in regard to corrective lenses—long before Galileo, who is also often credited considerably later with the telescope. It is most likely that the glassmaker ʿAbbas ibn Firnas in the ninth century and the polymath Ibn al-Haytham in the eleventh century should be credited with inventing early versions of corrective lenses, and in Italy Salvino d'Armate produced one of the earliest wearable spectacles around 1280, along with alternate credit also given to Fra Alessandro da Spina of Pisa about the same time, both not long after Bacon, who may have influenced them. Bacon's own words in *De iride* (on the rainbow) around 1235 suggest that lenses enable one "to correctly read the tiniest letters at very great distances." This does seem an ambiguous possible precedent for both spectacles and telescopes. Working telescopes seem to appear only after 1608 in northern European workshops of Hans Lippershey, Zacharias Janssen, and Jacob Metius almost simultaneously. Nonetheless, as a pioneer in optics, Bacon did make and use optical lenses. He was also probably the first European to fairly correctly theorize and describe the visible light spectrum as it is known today, which is a considerable achievement in itself.

By experimental observation, Bacon correctly observed the breaking up and separation of sunlight through water and the prism derived from it. Refraction of sunlight was not well known in Europe, described by Arab opticians like the eleventh century Ibn al-Haytham, whose *Kitāb al-manāẓir* (wr. 1011-1021; book of optics) Bacon read carefully. However, Bacon described the range of colored light as progressing from red hues through orange, yellow and green to blue and violet hues, what we now understand as the visible infrared to ultraviolet range (650-350 nanometers in reverse order). In addition, Bacon also correctly measured the maximum altitude of the angle of intensity as around 42°, which could only have been understood by direct observation and empirical experimentation over multiple, repeated events. Thus, Bacon long anticipated Sir Isaac Newton's (1642-1727) prism experiments and the phenomenon Newton named the spectrum.

stood as alchemy, it is difficult to verify that Bacon did anything more than experiment with metals and minerals.

Bacon's major writing appears around 1267 in the *Opus majus* (major work), an 800-page proposal for an encyclopedic book on the sciences, where most of his seminal ideas on science appear. This work was mostly at the request of an apparently enlightened pope, Clement IV, whom Bacon had known for decades first as Cardinal Gui Foulques and under whose protection he served and wrote after Foulques became pope in 1265. Bacon also wrote an *Opus minor* (minor work) and an *Opus tertium* (third work). Unfortunately, although the pope received Bacon's treatise, he died soon thereafter in 1268, and Bacon was subject to less enlightened minds in the Church. Having returned to Oxford to the Franciscan friary around 1278, over the next years between 1280 and 1286 Bacon also possibly wrote his *Communia naturalium* (general principles of natural philosophy) and the *Communia mathematica* (general principles of mathematical science), although some of these writings were possibly suppressed because his theology was not in accord with the Church.

Bacon died around 1292 in Oxford as a member of the Franciscan priory. Shortly thereafter, he became known as Doctor Mirabilis (wonderful teacher) by those who followed him.

IMPACT

Scientists following Bacon gradually began to understand his enormous range of interests and the value of empirical experiment over perceived authority. Rationalism and empiricism did not find common intellectual acceptance until the Renaissance and afterward, so in some sense Bacon was ahead of his time.

Bacon's work in optics and on light anticipated Galileo (1564-1642) and Sir Isaac Newton (1642-1727) by about four centuries; his work on reversing lenses and a probable telescope invention likewise are in advance of instrumentation of the microscope in the inventions of Zacharias Janssen (c. 1580-1638), Robert Hooke (1635-1703), and Antoni van Leeuwenhoek (1632-1723). Bacon's study of gunpowder and incendiaries became important in European warfare and reduced the role of castles and like defenses, helping to make feudalism obsolete. His insistence on linguistic accuracy and original biblical texts possibly even influenced John Wyclif (c. 1328-1384) in biblical studies in anticipation of the Reformation, where authority of text was more important than authority of tradition. Overall, Bacon has to be one of the greatest minds in the history of science.

—*Patrick Norman Hunt*

FURTHER READING

Clegg, Brian. *The First Scientist: A Life of Roger Bacon*. New York: Carroll & Graf, 2003. A good biography about how Bacon's life in the medieval monastic setting was in tension with the scientific pursuit of experimentation even in a potentially scholarly environment. A lively and plausible explanation of Bacon's life and his methods of empirical research in physics and mathematics as well as who and what influenced him.

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Hackett, Jeremiah M. "Adelard of Bath and Roger Bacon: Early English Natural Philosophers and Scientists" *Endeavor* 26, no. 2 (2002): 70-74. Shows Bacon not as "a medieval philosopher with scientific interests" but as a pioneer of scientific empiricism who had assimilated the best of Arabic mathematicians and physicists of optics.

Lindbergh, David, ed. *Roger Bacon's Philosophy of Nature: A Critical Edition*. South Bend, Ind.: St. Augustine's Press, 1997. Best for its excellent translations of selected Bacon texts of his *Opus Majus* and Lindbergh's modern explanations of what Bacon wrote about. The best critical readings of Bacon's thought as he actually wrote.

See also: ʿAbbas ibn Firnas; Aristotle; Galileo; Zacharias Janssen; Hans Lippershey; Sir Isaac Newton.

LEO HENDRIK BAEKELAND

Belgian chemist

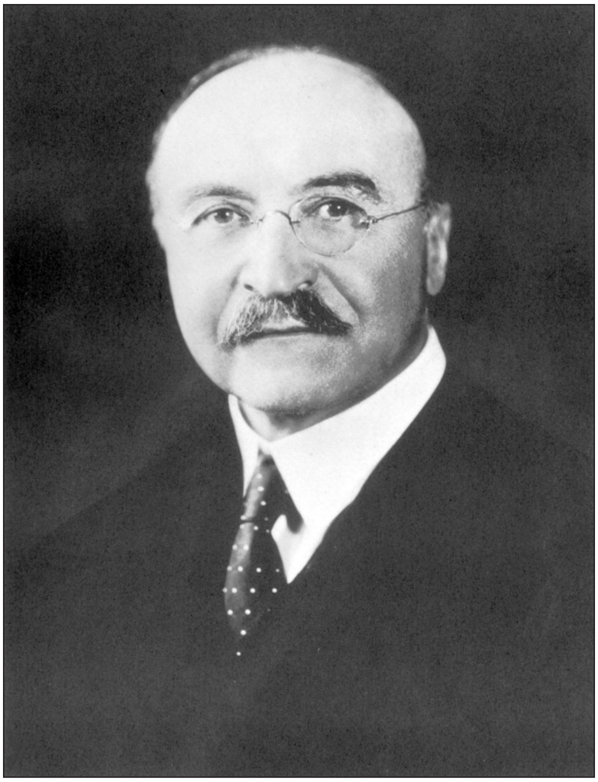
Baekeland's invention of Bakelite, the first thermosetting plastic, was critical to the industrial design of the Jazz Age by making it possible to produce large quantities of tough, durable plastic goods.

Born: November 14, 1863; Ghent, Belguim
Died: February 23, 1944; Beacon, New York
Primary field: Chemistry
Primary invention: Bakelite plastic

EARLY LIFE

Leo Hendrik Baekeland (BAYK-land) was born on November 14, 1863, in Ghent, Belgium. His father, an illiterate cobbler, wanted him to follow him into the shoemaker's trade and saw no purpose in formal education. By contrast, Leo's mother believed strongly in the value of education and saw that he received a solid foundation in the basics. When his father forced him to leave school and apprentice in the shoemaking trade, his mother encouraged him to take night courses. In spite of the difficulties of studying after having putting in a full day's work, he did well enough that he gained a scholarship that enabled him to attend the Ghent University, majoring in chemistry. In 1884, he completed his doctorate and subsequently became a research chemist and teacher.

Although he was a top student throughout his studies, he also had an irrepressible humorous streak that often



Leo Hendrik Baekeland, best known as the inventor of Bakelite, a popular plastic. (Getty Images) came out in the form of practical jokes. One joke, in which he painted a classmate's face with silver nitrate, came to the attention of school authorities when the frightened classmate went to a doctor who applied hydrochloric acid in an effort to remove the marks and instead burned his patient badly. When summoned before the board, Baekeland demonstrated the harmlessness of his prank by marking his own face with silver nitrate and then erasing it with a harmless chemical from a vial he had in his pocket. School officials were sufficiently mollified that Baekeland received only a mild reprimand, but as word got around about his classmate's injury, the physician's reputation was permanently damaged.

In 1889, Baekeland and his new wife, Celine, left for the United States, officially on leave from his university position. However, he soon found a position with Richard A. Anthony, Eastman Kodak's principal rival in the photographic business, and never looked back at academic life or Europe. His first assignment was to find a better way to make photographic paper for the growing amateur photographic market, which had grown explosively since George Eastman's introduction of the American film, a roll of paper negatives that could be loaded into a point-and-shoot camera. Baekeland was so successful that he was soon given steadily greater responsibility.

He subsequently formed his own company to produce a new kind of film, and he became independently wealthy when it was bought out by Eastman Kodak. He was then able to pursue his own chemical interests without having to worry about their marketability. As he grew bored with the chemistry of photography, he began to search out other aspects of chemistry to explore. Since his own financial situation was secure, he did not have any pressure to focus only on things that could be turned into marketable products quickly, and could risk going into blind alleys.

LIFE'S WORK

Baekeland became interested in the chemistry of phenol (a coal-tar derivative) and formaldehyde (a wood alcohol derivative). Coal tars were originally a noxious waste product of the industrial burning of coal as an energy source, and particularly of the great coking furnaces that turned coal into coke for steelmaking. These tars tended to accumulate in the smokestacks and had to be periodically cleaned out to prevent disastrous fires. In 1856, William Henry Perkin was attempting to create synthetic quinine, an antimalarial drug, out of coal tar and in the process discovered mauvine, the first of the synthetic organic dyes. The brilliant, colorfast purple rivaled the tyrean purple that had been made from the shells of small marine invertebrates in ancient times. However, while tyrean purple had been so rare and expensive as to be reserved for monarchs, mauvine was well within the reach of the burgeoning industrial middle class, whose hunger to ape the wealthy through the use of cheap industrial substitutes for previous luxury goods led to mauvine becoming so popular that the 1890's was known as the Mauve Decade.

In the half century that had followed, numerous uses had been developed for coal-tar derivatives, including various salves and ointments. However, the promise of phenol in the production of plastic substances had been continually frustrated. Although celluloid showed the value of a substance that could be produced and molded in industrial quantities, its dangerous flammability limited its popularity. Furthermore, the success of the electrical industry in the 1890's was rapidly making shellac, the only viable electrical insulator at the time, unaffordable.

Baekeland knew that German chemist Adolf von Baeyer had produced an impervious substance as a result of an explosive reaction between phenol and formaldehyde. The resulting substance was an unworkable lump, which led von Baeyer to dismiss it as useless. However, Baekeland wondered if there was some way to control the reaction. If it could be made to progress more slowly and evenly, it might produce something useful. In order to gain that control, he used a pressure vessel, which allowed him to cook the mixture at a far higher temperature and far longer than had been possible at atmospheric pressure.

Throughout the summer of 1907, Baekeland worked to perfect his new substance, certain he was on the brink of a major discovery. It started as a pourable resin but soon hardened into a translucent amber solid impervious to heat and solvents. Baekeland had succeeded in inventing the first thermosetting plastic. Unlike thermoplastics such as celluloid, which can be melted down and re-formed, thermosetting plastics form permanent molecular bonds as they cure.

Baekeland presented his new substance to the world under the trade name of Bakelite. Unlike earlier plastics, which often had proved to be commercial disappointments, Bakelite proved to be just the sort of artificial insulator the electrical industry needed so desperately. Furthermore, its hardness and elasticity approached that of ivory, making it the long sought-after ideal artificial billiard ball. Elephants would no longer need to be slaughtered to provide gentlemen with their pastime.

Bakelite

Throughout the nineteenth century, chemists and industrialists had searched for a cheap artificial substitute for a number of natural substances that were becoming increasingly rare. In particular, the rise of the middle class had led to a sharp increase in interest in the game of billiards and to a voracious demand for ivory to produce the balls. Because only a small portion of an elephant's tusk was suitable for making billiard balls, and because there was no way to determine if a given tusk had any suitable sections while still on the animal, entire herds of elephants were slaughtered to gain a few usable tusks. There was a very real concern that both African and Asian elephants might be driven extinct because of this relentless persecution.

As a result, there was strong pressure to produce an artificial substitute for ivory, and prizes were offered for the inventor who could produce a suitable substance. However, early work with various forms of nitrocellulose soaked in camphor produced only marginal results. In particular, such early plastics as collodion and celluloid retained the explosive characteristics of nitrocellulose, which had been originally developed as a smokeless substitute for gunpowder. One saloon owner who had been sent a sample of artificial billiard balls made of wood coated in celluloid complained that his patrons had a woeful tendency to draw their weapons when the balls struck together, since they produced a gunshot-like report rather than a soft click.

In addition, both collodion and celluloid were apt to lose their shape or even melt altogether if heated below their ignition point. Many owners of celluloid objects were quite disappointed to find a sticky mess under a sunlit window. The development of modern electrification created even further demand for a cheap substitute for natural substances, since shellac, the only good insulator for wiring, was in increasingly short supply.

When Leo Hendrik Baekeland discovered that a combination of phenol and formaldehyde, cooked at both high temperature and high pressure, would produce a resinous substance that cured into a hard, resilient solid impervious to both heat and solvents, his work was hailed as a miracle substance. It could be molded into just about any shape, although smooth curves with a slight angle, or draft, slid out of their molds more successfully than straight sides and sharp angles. It also readily took just about any color, which meant that it could be made to simulate the appearance of a variety of natural substances that were becoming difficult to obtain, including ivory, tortoiseshell, and rare tropical woods. Equally it could be made in forms that reveled in their artificial nature, including primary colors far too pure for any natural material.

The infant discipline of industrial design quickly embraced the possibility of Bakelite in creating new products for the new era. As domestic electrification moved from the very wealthy to a broad base of urban Americans in the 1920's, a whole range of appliances were created that frequently used Bakelite. The substance could be used to insulate against both heat and electricity or as an aesthetically pleasing case for a rat's nest of components. Because the molding process was most favorable to gently curved lines and because the Jazz Age had connected streamlining with not only speed but also modernity, many appliances such as radios were given sleek styling that would later be called the Art Deco look.

Industry quickly found thousands of uses for Bakelite, creating the first plastic age. The Bell System molded telephone cases from Bakelite, creating the characteristic desk sets of the early twentieth century. The developing radio receiver industry of the Jazz Age also found Bakelite an excellent substance for injection molding to produce inexpensive cases that could even be made to look like the wood used in more expensive models, or could be allowed to revel in their "syntheticness" for a futuristic look. The flexibility of Bakelite, along with the era's fascination with speed and streamlining, was a major factor in the development of the Art Deco style. By the late 1920's, forty-three industries had found a use for Baekeland's wonder substance.

Baekeland himself made the cover of *Time* magazine on September 22, 1924. In the 1930's, he became involved in the public debate over what should be the generic name for the family of substances to which Bakelite belonged. He quickly vetoed such outré terms as "synthoid," which he derided as having no meaning, although his own preferred term "resinoid" fared no better. The court of public opinion would ultimately settle upon "plastic" for the entire family of moldable substances and would identify individual types by their formulations: phenolic plastics, polyvinyl chloride (PVC), and so forth.

In 1939, Baekeland sold his company to Union Carbide. By this time, he had been in semiretirement for a number of years and had been spending most of his time in Coconut Grove, Florida, where he owned the former estate of William Jennings Bryan. He shared Bryan's pacifist leanings, and up to the attack on Pearl Harbor he strove to keep the United States out of World War II. He died on February 23, 1944, disappointed to see the world engulfed yet again in destructive war, but before the horrors of the Holocaust were revealed.

IMPACT

The inventor of the first thermosetting plastic, Leo Hendrik Baekeland was in a very real sense the "father of the plastic age." Although Bakelite has since been superseded by other plastics such as PVC, nylon, and polystyrene, its success was an important foundation for the wealth of inexpensive consumer goods that poured into the market during the Jazz Age. For the first time, products could be formed quickly and easily in enormous quantities from materials that had previously been regarded as industrial waste.

—*Leigh Husband Kimmel*

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See also: George Eastman; Earl S. Tupper.

ALEXANDER BAIN

Scottish engineer

Bain pioneered various applications of electricity in clockmaking and made significant contributions to the development of telegraphy, including a copying machine that is now recognized as the ancestor of the modern fax machine.

Born: October 10, 1810; Watten, Caithness, Scotland
Died: January 2, 1877; Kirkintilloch, near Glasgow, Scotland
Primary fields: Communications; electronics and electrical engineering
Primary inventions: Facsimile machine; chemical telegraph

EARLY LIFE

Alexander Bain was the fifth of the eleven children of John Bain, a crofter, and Isobel Waiter, who lived in a cottage at Leanmore, between the towns of Thurso and Wick in Caithness in the far north of Scotland. He was one of a pair of non-identical twins, the other being his sister Margaret. He received his elementary education at Blacklass village school before being apprenticed to a watchmaker, John Sellars, in Wick.

In 1837, Bain went to London and worked as a journeyman clockmaker in Clerkenwell. His employer was probably John Barwise, the "chronomoter maker" who was Bain's coapplicant for his first patent in 1841. It is not known whether Bain's employer was the same Clerkenwell clockmaker that William Fothergill Cooke had hired in April, 1836, to make a model of his first telegraph apparatus, but it is not unlikely. Bain took advantage of the opportunities London offered to attend lectures, exhibitions, and demonstrations of electrical phenomena and technology and became fascinated by the possibility of making use of electricity in clocks. He began applying for patents for such applications, the first of which was granted on January 11, 1841, to him and Barwise for a clock whose pendulum was moved by electromagnetic impulses.

Charles Wheatstone had demonstrated a clock to the Royal Society in December, 1840, similar to the one that Bain and Barwise patented, and Bain put about the story that he had visited Wheatstone on the recommendation of a magazine editor and that Wheatstone had stolen his design after advising him not to bother taking the idea further. Wheatstone claimed to have been working on his electric clock long before meeting Bain, and it is entirely likely that the two men came up with the idea independently.

LIFE'S WORK

The ten years following 1841 were an extraordinarily fertile period for Bain. In December of that year, he and Lieutenant Thomas Wright—also a Clerkenwell resident—took out a patent for a series of applications of electric technology to railway locomotives and signaling. Bain then introduced a crucial modification to telegraph transmission and reception, "inverting" the existing method of signaling, which used a needle pivoting under the influence of an electromagnet by suspending a movable coil between the poles of a magnet. On May 27, 1843, Bain patented a transmitting and receiving apparatus that could scan drawings and documents, which is now recognized as the ancestor of the fax machine.

Although the image-transmitting device attracted some publicity and contributed to Bain's being described in *The Times* as "a most imaginative and meritorious inventor" in April, 1844, it was ahead of its time and did not give rise to any immediate practical applications. Italian physicist Giovanni Caselli subsequently built a giant version with an eight-foot pendulum that he called the pantelegraph, which sent a message from Paris to Amiens in 1856 and was used in a Paris-Lyon line between 1865 and 1870. An invention of greater practical potential in the mid-nineteenth century was the chemical telegraph that Bain patented on December 12, 1846, which recorded signals at a telegraph receiving station by recording impulses on paper impregnated with an electromagnetically sensitive solution, on the same principle as the 1843 image transmitter.

On May 15, 1844, Bain married a widow named Matilda Bowe, née Davis; they had two sons and two daughters before she died in 1856. The family had apparently moved to Edinburgh by the end of 1846; the chemical telegraph patent was filed from there. When the Electric Telegraph Company was set up in 1846 by William Fothergill Cooke and John Lewis Ricardo, Bain complained that its devices infringed one of his earlier patents, and he gave evidence in support of his claim to select committees of both houses of Parliament. The company's sponsors were ordered to award him a payment of £7,500, which was a large sum by his own standards, although it was very much smaller than the payments the sponsors made to Cooke and Wheatstone, the other holders of the key patents in the field.

The payment Bain received from the Electric Telegraph Company enabled him to open a showroom and manufactory at 43 Old Bond Street in the heart of London's West End. In the Great Exhibition of 1851, he was awarded an exhibition medal for his clocks, and in May, 1852, his family was living at Beevor Lodge in Hammersmith. He probably overstretched his resources in funding this change of lifestyle; at any rate, his fortunes soon took a turn for the worse. He did not patent any further inventions of note after 1852, perhaps because he had decided to direct his energies to the exploitation of the chemical telegraph system.

Bain developed an automatic transmitting system using punched tape that enabled messages to be sent at the much higher speeds that the chemical receiver made possible, and his entire system transmitted and received information much more rapidly than the mechanical systems then in use. His system was first adopted for development in the United States by Henry O'Reilly and was subsequently taken up by others, but Samuel F. B. Morse and his associates immediately set out to kill it off, lest it supersede their own, much slower apparatus. Morse claimed patent infringement on the slender grounds that

THE FAX MACHINE

In 1843, Alexander Bain received a British patent for his fax machine, titled "improvements in producing and regulating electric currents and improvements in timepieces and in electric printing and signal telegraphs." Bain's device—he did not, of course, use the term "fax machine," which is a conspicuously modern invention—employed a pair of carefully synchronized pendulums, one of which scanned a page containing text or a drawing, translating the presence of ink at a particular point on the page into an electrical impulse that could be reproduced at a remote location by causing paper impregnated with an electrochemically sensitive solution (a mixture of ammonium nitrate and potassium ferrocyanide) to darken at the equivalent point. Bain's fax machine did not catch on; nevertheless, Giovanni Caselli's pantelegraph was based on Bain's invention. Caselli's device became the first commercial fax machine, operating between Paris and Lyon from 1865 to 1870.

Bain applied for a new patent of an improved version of his copier in 1850 but could not obtain one because Frederick Bakewell had already obtained a patent for his own image telegraph in 1848; whether the latter should have been granted, in view of Bain's 1843 patent, is arguable, but as neither inventor managed to produce a marketable machine at the time, the question is probably irrelevant. The modern fax machine, however, uses the same principle, and its reinventors have been happy to give due credit to Bain for his remarkable anticipation. Indeed, Bain's fax machine was surely ahead of its time: It was not until the 1980's, about 140 years after Bain's patent was granted, that the fax machine saw widespread use.

the paper tape used in the automatic transmitter was his design, and that the alphabet used in signaling was also his intellectual property, although he had not invented it. The attempt to defend the case presumably drained Bain's resources and left him in dire straits, but there is no record of his activities in the late 1850's and throughout the 1860's, probably because he was not in Great Britain for much of that time. An automatic transmitting system designed by Wheatstone was, however, integrated with conventional receiving devices in the Electric Telegraph Company's system; Bain again felt that he had been robbed, but he could obtain no recompense this time.

Bain's other inventions included an electronic log to record the progress of ships at sea, translating signals from vanes rotating under the surface, and an electrical sounding apparatus for use at sea. Some of his electric signaling devices for use on the railways and for communication between railway carriages were adopted for use, but he does not appear to have made any money from them. He worked on dedicated telegraph systems for the use of fire and police services, but he was unable to get them adopted. He also invented a device enabling musical instruments to be played at a distance (a device of a sort pioneered by Wheatstone), a spill-proof inkwell, and a propelling pencil. He attempted some improvements to repeating firearms.

By 1872, Bain was back in Scotland repairing clocks for a living. He did some work for Lord Kelvin (William Thomson), an ingenious inventor who understood the import of Bain's innovations, having employed a variant of Bain's "inverted needle" system in his own siphon recorder. Kelvin took up his cause and managed to procure Bain a pension of £80 per year, beginning in 1873, and a grant of £150 from the Royal Society. Bain was in poor health by then, however, and when he lost the use of his legs Kelvin had to recommend him for admission to the Broomhill Home for Incurables at Kirkintilloch. After dying there, Bain was buried in the nearby Old Aisle Cemetery. His two sons survived him, but neither was living in Britain in the 1870's. One had emigrated to the United States, and the other was apparently resident somewhere in continental Europe.

IMPACT

In an era when so many inventors made money from their inventions, Bain suffered more than his fair share of misfortune—a circumstance probably connected to the fact that he was a highland Scotsman of humble origin and was thus regarded with a degree of contempt in England. Had he and the users of his chemical telegraph system been able to defend it successfully against the more aggressive and worldly wise Samuel Morse and his richer associates, that technology might have been standardized alongside systems translating received messages into sound, but the battle was fought on foreign soil against opponents who far outweighed him in terms of their resources. His copying systems—which were, in hindsight, much more interesting and potentially valuable than they seemed at the time—never won him the credit or the reward they warranted while he was alive. For these reasons, the direct impact of Bain's life and works was much less than it might have been, and it was left to historians of technology to provide respectful testimony to his awesome ingenuity.

—*Brian Stableford*

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sources, in spite of the fact that it compensates for a lack of hard information with dubious and colorfully expressed conjecture.

See also: Alexander Graham Bell; William Fothergill Cooke; Thomas Alva Edison; Elisha Gray; Lord Kelvin; Samuel F. B. Morse; Charles Wheatstone.

BENJAMIN BANNEKER

American mathematician and astronomer

Banneker was a largely self-educated African American astronomer. The series of almanacs he produced between 1792 and 1797 served to bring him international attention, both for their scientific content and for the role they played in the struggle against slavery.

Born: November 9, 1731; Baltimore County, Maryland
Died: October 9, 1806; Baltimore County, Maryland
Primary fields: Astronomy; mathematics
Primary inventions: Wooden striking clock; Banneker's almanac

EARLY LIFE

Benjamin Banneker (BAN-eh-kur) was born in Baltimore County, Maryland, on November 9, 1731. His grandmother was an English indentured servant named Molly Welsh who arrived in Maryland in the early 1680's and later married a former slave known as Bannka, Bannaka, or Banneka. Their oldest child, Mary (Benjamin's mother), in turn also married a former slave who, since he had no last name of his own, took his wife's name, which eventually became Banneker.

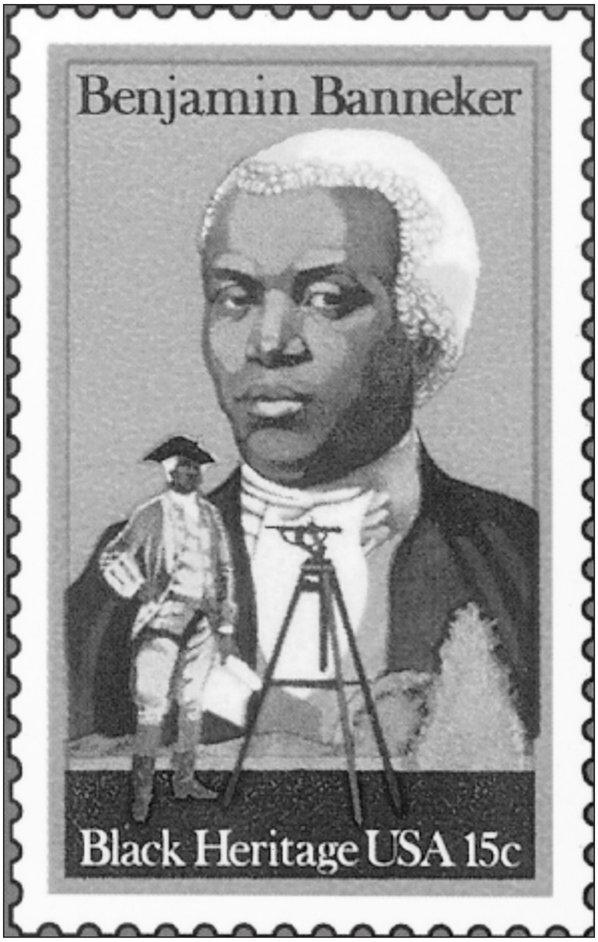
Benjamin grew up on his parents' farm, which was located close by the farm where his grandmother still resided. His grandmother, in fact, stands out as one of the important influences of his early years, instructing him in reading, writing, and religion and taking early note of his intellectual promise. She also arranged for him to attend a local Quaker school, where his intellectual gifts were further nurtured. He eventually demonstrated a particular ability in mathematics and practical mechanics and in his early twenties borrowed a watch that he studied in detail and used as a model for a clock of his own design and construction that became a source of local amazement. The clock, the inner workings of which were fashioned almost entirely of wood, struck the hours and continued to operate for more than fifty years until it was lost in a fire that destroyed Banneker's house at the time of his death in 1806. Following his own father's death in 1759, Benjamin took over the responsibility of running the family farm and had less time at his disposal to pursue his scientific and mechanical interests. He continued to read and educate himself as time permitted, and he also cultivated what was to become a lifelong interest in music, becoming a competent player of both the flute and the violin. For the most part, however, during the dozen or so years that followed he lived a quiet rural existence.

LIFE'S WORK

A major change occurred in Banneker's life in the early 1770's, when members of the Ellicott family—initially two brothers, John and Andrew—arrived in the area from Pennsylvania and began to construct a gristmill along the Patapsco River, just a short distance from the Banneker farm. This undertaking and the community that grew up in connection with it, known as Ellicott's Lower Mills, quickly captured Banneker's attention, while the workings of the mill itself served to expose him to the technological developments of the early stages of the Industrial Revolution. The Quaker background of the Ellicotts also offered a more enlightened racial outlook than that held by other whites in the area, some of whom seemed to have harassed Banneker at various times during his life.

Over the course of the years that followed, Banneker developed friendships with several members of the Ellicott family, drawing intellectual stimulation from the knowledge of science and technology that they brought into the area. With a third Ellicott brother, Joseph, who also settled in the community, Banneker shared a common interest in clockmaking, as this individual had also designed and built a clock that soon gained considerable local attention. Joseph Ellicott's clock, which was close to eight feet tall and was kept in the main hallway of his home, had four sides—the first showing the movements of the planets around the Sun, the second displaying time, the third listing and marking the names of twenty-four songs that played at each of the day's passing hours, and the fourth containing a glass window through which one could view the clock's inner workings. In many ways, these two local clocks, Banneker's wooden clock and Joseph Ellicott's far more complex technical achievement, serve to highlight the new level of scientific and technological sophistication that the arrival of the Ellicotts brought into Banneker's life.

Of all the Ellicotts, it was Andrew Ellicott's son George, a skilled land surveyor, mathematician, and astronomer, with whom Banneker developed the closest long-term relationship. Although separated by nearly thirty years in age—Banneker was forty-seven and George eighteen when they met—their shared interests provided an intellectual stimulus for both and would lead Banneker into what was to be his most important and productive period as a scientist. As time permitted after their initial meeting in 1778, Banneker and George Ellicott met and discussed their mutual areas of interest. In 1788, given his busy work schedule and lack of opportunity for pursuing his own scientific projects, Ellicott offered Banneker the use of some of his books on astronomy as well as some of the scientific instruments he had collected. Suspecting that Banneker would soon be making his own nighttime observations, Ellicott also provided him with a small wooden table and a tin candleholder to assist him with the recording of data.



Benjamin Banneker, 1980 commemorative U.S. postage stamp. (Arkent Archive)

Within a short period of time, Banneker was indeed using his nights to do astronomical observations and was soon undertaking the mathematical calculations of eclipses. This in turn led to an interest in producing an ephemeris, a compendium of astronomical facts and predictions, for one of the many almanacs that were being published in America at this time. Following several years of struggle and numerous setbacks for Banneker, his first almanac, entitled *Benjamin Banneker's Pennsylvania, Delaware, Maryland, and Virginia Almanack and Ephemeris, for the Year of Our Lord, 1792*, was published by the firm of Goddard and Angell in Baltimore in December, 1791. By that time, his work had come to the attention of then secretary of state Thomas Jefferson as well as several individuals prominent in the antislavery movement for the example it provided of the achievement potential of his race. The 1792 almanac was followed by similar annual publications in 1793-1797.

The year prior to the publication of his first almanac, and once again as a result of his connections with the Ellicott family, Banneker also participated in the land survey of the newly established District of Columbia. Following the passage of legislation in 1790 to create the District, Major Andrew Ellicott, the son of one of the original founders of the gristmill and community located near Banneker's farm, was chosen to undertake a survey of the new territory. Seeking individuals skilled in the use of scientific instruments and good at keeping accurate records, Ellicott first approached his cousin George to serve with him as an assistant. When George proved too busy with other work, he in turn suggested Banneker. Now close to sixty years old and seldom having ventured beyond the confines of his farm, Banneker nevertheless agreed to participate in the project. The survey, which began in February of 1791, proved to be a difficult undertaking. Living in a tent, engaging at night in the astronomical observations required by the project and then being unable to get sufficient rest during the day due to Andrew Ellicott's rigid dawn-to-dark, seven-day-a-week schedule, Banneker remained on the project until the latter part of April. Then, with the arrival of Andrew's younger brother Benjamin who was able to take over his role in the project, Banneker returned home to continue his own observations and study.

By the mid-1790's, Banneker's work had earned him both national and international attention. His almanacs were well known both in the United States and England, particularly among those engaged in the fight against slavery. The second edition of his almanac included a famous exchange of letters between Banneker and Thomas Jefferson on the subject of race as well as an essay against war by the prominent physician and writer Benjamin Rush. Subsequent issues of his almanac also included material dealing with the abolition cause and racial equality.

Following the publication of his last almanac in 1797, Banneker's life returned in large part to its earlier pattern of rural simplicity. Banneker's health gradually declined as he entered his final years. He continued to live alone, having never married, and to take care of himself. He kept a journal that included his thoughts and observations on nature and other subjects. He died peacefully at home following a morning walk on October 9, 1806.

BANNEKER'S WOODEN STRIKING CLOCK

While not an inventor per se (being best known for his astronomical calculations and almanacs), Benjamin Banneker is nevertheless remembered for the amazing wooden striking clock that he designed and built while still in his early twenties. Living an isolated existence as a free black in rural Maryland in the mid-eighteenth century, Banneker had little initial exposure to the scientific and technological discoveries of his day. Intrigued by a pocket watch that he saw one day and subsequently borrowed, he studied the instrument in great detail and determined to build a working clock of his own. Envisioning the problem of his clock's design as a kind of mathematical puzzle, he first calculated and diagrammed its inner works, then carefully and meticulously carved the individual parts out of hard wood, spending many hours modifying each part during the process of assembly.

The completed work was thus constructed almost entirely of wood. It had a hand-inscribed dial plate and carved wooden hands, and it accurately struck the hours of the day. The clock continued to operate for more than fifty years until it was destroyed in a fire at the time of his death in 1806. Sadly, the clock's destruction in the fire eliminated the possibility of knowing its precise design. Its existence, however, has been fully documented by Banneker's principal biographer, Silvio Bedini—an important point since so much of Banneker's life has entered the realm of legend. Throughout Banneker's lifetime, the clock remained a source of amazement to local citizens as well as to travelers to the area. While clearly not as significant as his other scientific work, Banneker's wooden striking clock nonetheless serves to highlight the amazing genius of this eighteenth century African American astronomer and scientist.

IMPACT

Banneker was a man of significant natural gifts. With almost no formal education, and living a quiet rural existence as a free black man in a state that still practiced slavery, he gained international recognition as an astronomer and mathematician. The series of almanacs that he published between 1792 and 1797 and the astronomical facts and calculations they contained were the chief source of his fame, but of close to equal importance was the social significance given to these works. Viewed and considered by individuals as prominent as Jefferson, the works helped to challenge the existing racial stereotypes of the age. Banneker's relationship with members of the Ellicott family, whose presence in his home region played an important part in his success, also offers an interesting example of enlightened race relations during the period as well as providing evidence of the manner in which scientific knowledge was disseminated and exchanged in eighteenth century America. Finally, his daily notes and journals provide valuable insights into the manner in which he worked as well as the way his methods evolved over time, information not widely available for other astronomers and ephemeris-producers of the period.

—*Scott Wright*

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See also: George Washington Carver; Thomas Jefferson.

JOHN BARDEEN

American physicist and electrical engineer

Bardeen's collaborative work led to the discovery of the transistor effect and to the development of a notable theory of superconductivity that resulted in his becoming the first person in history to win two Nobel Prizes in the same field—physics—one in 1956 and another in 1972.

Born: May 23, 1908; Madison, Wisconsin
Died: January 30, 1991; Boston, Massachusetts
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Transistor; superconductivity theory

EARLY LIFE

John Bardeen was the son of Charles R. and Althea Harmer Bardeen. His father, a physician and professor of anatomy, was the founding dean of the University of Wisconsin Medical School in Madison, where John was raised. His mother was a teacher who was once associated with the Dewey Laboratory School at the University of Chicago.

Althea was instrumental in teaching John how to solve problems: break them down into their component parts, then work on solving each of these manageable parts. In his later life, this is precisely the way Bardeen approached the baffling problems on which he was working in physics. He also was exposed to progressive problem-solving techniques as a student at the University High School of the University of Wisconsin, which John entered after completing the third grade of elementary school. He completed high school when he was thirteen, but he took two more years of instruction at Madison Central High School (1921-1923) because Charles felt his son was too young and undeveloped socially to enter college.

When John was ten, his mother was diagnosed with cancer. Her children were shielded from the seriousness of her illness, but she was often away in Chicago for radiation and other treatments. Her children were stunned by her death in 1920. John's schoolwork suffered a temporary decline as he dealt with losing his mother.

The young man entered the University of Wisconsin in 1923 to study electrical engineering. As a student there, Bardeen encountered many impressive scientists and mathematicians. He took a tutorial with Warren Weaver, who encouraged Bardeen's mathematical development and who later became head of the Rockefeller Foundation's science program. Bardeen also studied with John Van Vleck, who introduced modern quantum mechanics to the midwestern campus and with whom Bardeen later was associated as a postdoctoral fellow at Harvard University, where Van Vleck was then teaching.

Bardeen postponed his college graduation for a year by taking extra courses and working for the Western Electric Company. Upon graduation in 1928, he had completed much of the course work for a master's degree, so he stayed on, receiving a master's degree in electrical engineering in 1929. He was recruited by the American Telephone and Telegraph Company (AT&T) to work on the diffraction of radio-length electromagnetic waves and antenna design, but before he could begin, a hiring freeze was imposed, so Bardeen went to work instead as a geophysicist for Gulf Oil.

LIFE'S WORK

When his interests veered more toward theoretical than applied physics, Bardeen decided to leave his secure job with Gulf Oil and enter the doctoral program in mathematics at Princeton University, to which many eminent German-Jewish mathematicians and physicists, including Albert Einstein, had flocked in an effort to escape Nazi Germany. He completed his doctorate in mathematical physics there in 1936, doing much of his research under his major professor, E. P. Wigner, who supervised the work of many students who later became some of the world's most celebrated figures in solid-state physics.

The night before he left for Princeton, Bardeen met Jane Maxwell, who taught at the Carnegie Institute of Technology and was a graduate student at the University of Pittsburgh. He visited her in Pittsburgh as often as he could. From 1935 until 1938, he was a junior fellow of the Society of Fellows at Harvard University, and in 1938, shortly after accepting a position as assistant professor of physics at the University of Minnesota, he married Jane. The couple subsequently had three children.

Bardeen was a self-effacing man with so soft a voice that some people referred to him as "the whisperer." He always preferred to work collaboratively with people in his field rather than pursue his research alone. After World War II, during which Bardeen was the principal physicist for the U.S. Naval Ordnance Laboratory in Washington, D.C., he was brought to Bell Telephone Laboratories in 1946 by William Shockley, whom Bardeen knew from their Harvard days. At Bardeen's urging, Shockley also brought Walter H. Brattain, a classmate of Bardeen in graduate school, to Bell Labs. The three collaborated on semiconduction, which led to their discovery of the transistor effect in 1947, for which the three shared the 1956 Nobel Prize in Physics.

The importance of the development of transistors cannot be overstated. Transistors are electronic devices made from semiconductor material capable of amplifying electrical signals, thereby bringing about many advances in technology. Bardeen's years in the Naval Ordnance Laboratory, where he worked on underwater ordnance and minesweeping, led inevitably to the work he did at Bell Labs. The transistor effect has broad implications for computers, radios, television broadcasting, satellite technology, industrial control systems, and navigation. Bardeen's work in this field also led directly to his subsequent work on the theory of superconductivity, for which he shared the 1972 Nobel Prize in Physics with Leon N. Cooper and John Robert Schrieffer.

Superconductivity has to do with the electrical reactions in metals and alloys whose temperature is reduced drastically, causing them to lose their resistance. Because of this lack of resistance in a superconducting circuit, when the temperature of the metal involved reaches absolute zero (–273.13° Celsius), the electrical current flows continuously. The implications of this for the generation of electrical power are immeasurable and are of sufficient importance that a great deal of subsequent research in the field has focused on achieving superconductivity at temperatures higher than absolute zero.

Bardeen left Bell Labs in 1951 to join the University

The Transistor

The understanding of the transistor effect stems from the observation that when an atom of phosphorus is forced upon an atom of silicon (replaced by germanium in later experiments), it contributes a negative electron to the silicon. On the other hand, when an atom of boron is forced upon an atom of silicon or germanium, it contributes a positive charge to the silicon or germanium and leaves a hole in the atomic structure that can migrate in semiconductors, thereby acting as a carrier of a positive charge.

On December 16, 1947, John Bardeen and Walter H. Brattain inserted two electrodes into a half-inch-long shred of germanium. They found that the electrical charge the germanium emitted was over one hundred times stronger than the charge that went in. This marked the beginning of transistors and of the information age. Bardeen and his colleagues initially were seeking to understand how to control rectifiers by adding an extra electrode. When they injected a positive probe close to a negative electrode, however, they discovered the transistor action that led to their understanding of the transistor effect. This theoretical understanding, in turn, eventually led, on an applied level, to the invention of transistors.

Transistors revolutionized the entire world of electronics on which modern society is so dependent. Whereas the vacuum tubes that were generally used as sources of power in their earliest electronic applications were large and cumbersome, transistors weigh little and are tiny. They can be mass-produced quickly and inexpensively. They are ideal for battery-powered uses because of the low voltages at which they can be operated.

Unlike vacuum tubes, transistors require no warm-up time but spring into action the moment the power source is engaged. They use power sparingly, so are notably power-efficient. They are generally rugged physically, although they can be subjected to interference from some electrical and magnetic fields. Transistors generally have a long life. Some have been in constant use since the late 1970's and are still operating. They can also control currents of several hundred amperes, which gives them a wide range of powerful uses.

Of considerable importance to such applications as the launching of spacecraft is the transistor's insensitivity to mechanical shock and heavy vibration. Transistors have made the exploration of space feasible because of their ability to withstand the vibrations involved in the launching of spacecraft.

The invention of the transistor has been called the most significant development of the twentieth century, and such a claim is not exaggerated. In an electronic age, the transistor affects the lives of everyone.

of Illinois at Urbana-Champaign as a professor of electrical engineering and physics. Working there in collaboration with Cooper and Schrieffer, he agonized over the theoretical aspects of superconductivity. Working mostly with little more than paper and pencils and examining closely all of the most significant theories of superconductivity, he and his colleagues unlocked the secret of the phenomenon, which is generally referred to as the BCS (Bardeen-Cooper-Schrieffer) theory. The method Bardeen, Cooper, and Schrieffer employed in dealing with the theoretical problems posed by their investigations provided a method for dealing with other physical problems. Their collaboration applied directly, for example, to understanding elementary particle theory.

From 1959 until his retirement in 1975, Bardeen taught at the Center for Advanced Study at the University of Illinois. He died of heart failure in Boston on January 30, 1991.

IMPACT

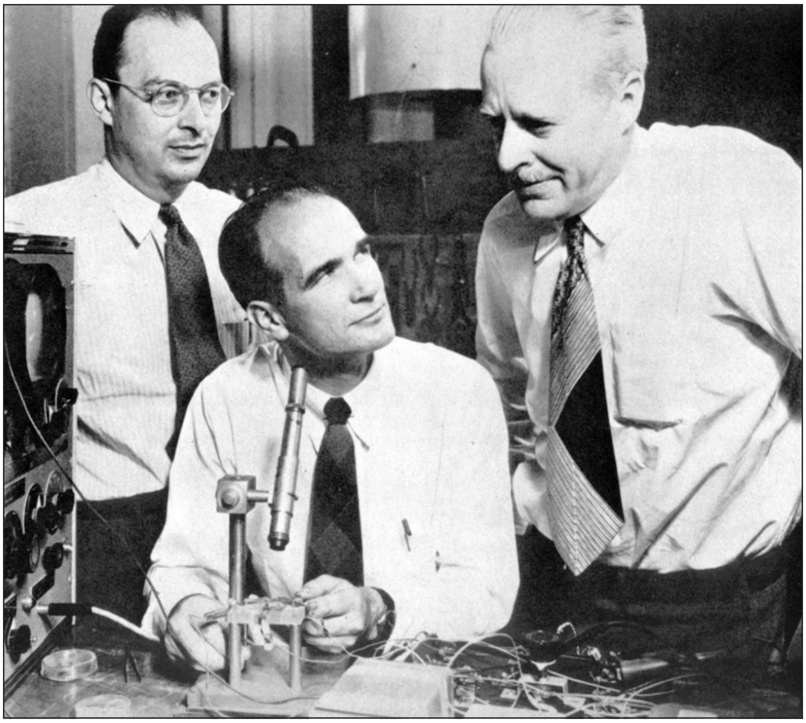
Were it not for the pioneering work of Bardeen, Shockley, and Brattain, the world would be much different today. There were computer systems as early as the 1940's, but they were powered by vacuum tubes that were large, cumbersome, and undependable. Physicist Miles Klein told an interviewer that the invention of the transistor and everything that grew out of it began an industrial revolution that was as equally as important as the first.

A machine called the Electronic Numerical Integrator and Computer (ENIAC) was developed by John Presper Eckert and John William Mauchly between 1943 and 1945 and was built at the Moore School of Electrical Engineering of the University of Pennsylvania. After the pair left the university, they set up their own company and produced the Universal Automatic Computer (UNIVAC), selling the first one to the U.S. Census Bureau in 1951. This computer could perform 1,905 operations per second, but it required 35.5 square meters of floor space and consumed power at a daunting rate. It originally cost $159,000, but the cost quickly rose to close to $1.5 million per unit, making it unobtainable for most colleges and universities as well as for industry.

Once the transistor was perfected, computers had a greatly increased capacity to carry out operations. Such computers were miniaturized to the point that they could sit on users' desks or even be held in the hand. The operations performed by the original UNIVAC soon were exceeded enormously by the relatively light personal computers (PCs) upon which many people currently depend.

Without transistors, it would have been impossible to engage in the sort of space exploration that has resulted in putting humans on the Moon and in establishing the International Space Station, which is in low Earth orbit at 17,210 miles per hour between 217 and 286 statute miles above Earth. Transistors have also made possible sophisticated medical hardware and complicated television sets, including high definition.

Bardeen's research has paved the way to finding methods of achieving superconductivity at temperatures well above absolute zero. The practical outcomes of doing so are incalculable. When superconductivity is



From left: John Bardeen, William Shockley, and Walter H. Brattain working at Bell Labs in Murray Hill, New Jersey, in 1956. The three men shared that year's Nobel Prize in Physics for their discovery of the transistor effect in 1947. (AP/Wide World Photos) achieved at higher temperatures, many of the energy problems facing the world today should be greatly diminished.

—*R. Baird Shuman*

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See also: Walter H. Brattain; John Presper Eckert; Nick Holonyak, Jr.; Jack St. Clair Kilby; John William Mauchly; Karl Alexander Müller; Stanford Ovshinsky; Gerald Pearson; Claude Elwood Shannon; William Shockley.

PATRICIA BATH

American opthalmologist

A lifelong advocate for the blind, Bath introduced a safe and accurate laser surgery device and method for the removal of cataracts.

Born: November 4, 1942; Harlem, New York
Also known as: Patricia Era Bath (full name)
Primary field: Medicine and medical technology
Primary invention: Laserphaco probe

EARLY LIFE

Patricia Era Bath was born to Rupert and Gladys Bath in Harlem, New York. Rupert Bath was an immigrant from Trinidad, British West Indies, and her American mother was the descendant of African slaves and Cherokee Native Americans. Her father worked in a variety of jobs; he served as a motorman for the New York City subway, a merchant seaman, and a newspaper columnist. Her mother was a housewife who also worked as a domestic, one of the few positions open for African American women in the 1940's, in order to save money for her children's education.

Bath was interested in problem solving from childhood. This interest was encouraged at Charles Evans Hughes High School in New York, where she took biology courses that first sparked her interest in the sciences. She excelled in school and earned numerous awards. She applied for a National Science Foundation Scholarship and was chosen in 1959 to work in a summer program for high school students at Yeshiva University. She was also able to work with the university and Harlem Hospital on cancer research. During this time, she worked with Rabbi Moses D. Tendler and Dr. Robert O. Bernard; it was her job to collect and analyze information in an effort to forecast the progression of cancer cells. She coauthored a research report presented at the Fifth Annual International Congress on Nutrition in Washington, D.C., on September 2, 1960. That same year, she won a Merit Award from *Mademoiselle* magazine. Bath completed high school in just two and a half years.

Bath's higher education began at Hunter College in New York, where she graduated with a bachelor's degree

THE LASERPHACO PROBE

Dr. Patricia Bath began work on an invention for laser cataract surgery in 1981. Unable to find the appropriate lasers in the United States, she traveled to Berlin, Germany, where she studied the latest laser technology as she designed her "apparatus for ablating and removing cataract lenses," later called the laserphaco probe. Once the invention was complete, she successfully tested it on human cadavers. Her device was first used on live human subjects seven years after she began experiments, and she was awarded a patent for her laserphaco probe in 1988.

Bath's procedure uses a laser to destroy and remove the cataract coating of the eye. A flexible line (less than one millimeter in diameter) is inserted through an incision in the lens until it is next to the cataract. Low amounts of coherent radiation then blast the cataract by an optical fiber in the line. The line also contains a tube for irrigating the eye and a tube for removing the ablated pieces of the cataract during the procedure. A new lens is then inserted into the eye to replace the lens that held the cataract.

Bath's laser probe method was revolutionary in its ability to remove cataracts safely. It replaced traditional methods, the most common of which used a drill-like device to grind the cataract. This outdated technique was sometimes inexact and potentially harmful.

in chemistry in 1964. She continued her graduate education at Howard University Medical School, graduating with a medical degree in 1968. This was followed by an internship at Harlem Hospital (1968-1969), a fellowship at Columbia University (1969-1970), and a residency at New York University (1970-1973).

LIFE'S WORK

In 1967, while at Howard, Bath traveled to Yugoslavia to study children's health issues. A year later, she joined the Poor People's Campaign as they marched in Washington, D.C., for economic rights. After graduating from Howard, she studied ophthalmology at Columbia and became an assistant of surgery at hospitals throughout New York. During the following years, she traveled to Africa to serve as chief of ophthalmology at Mercy Hospital in Nigeria. She also worked with the White House Counsel for a National and International Blindness Prevention Program for two years.

Bath became interested in working with the visually impaired while she was at Columbia University. While serving at the Eye Clinic in Harlem, she observed a large number of African Americans suffering from vision problems. In a well-received report, she concluded that African Americans were twice as likely as the general population to suffer from blindness. Moreover, the study showed that African Americans were eight times more likely than whites to suffer from glaucoma-related blindness. Her work prompted her to create the practice of community ophthalmology, in which volunteers visit underserved communities to screen for vision problems.

In 1973, Bath completed her residency in ophthalmology at New York University. That year, she moved to California to join the faculty at the University of California, Los Angeles (UCLA), and Charles R. Drew University. In 1976, she cofounded the American Institute for the Prevention of Blindness. In 1983, she cofounded and chaired the Ophthalmology Residency Training Program at UCLA-Drew.

One of Bath's main areas of interest was cataract disease. A cataract is a clouding of the lens of the eye that can impair vision and sometimes cause blindness. Bath began researching laser surgery as a treatment for vision problems, and her research took her to Germany to study the latest technology. By 1986, she had designed a laser instrument for removing cataracts and successfully tested it. Bath's laser surgery method was faster, safer, and more accurate than traditional methods of cataract surgery.

Bath was granted U.S. Patent number 4,744,360 on May 17, 1988, for her laserphaco probe, becoming the first African American woman to be awarded a patent for a medical invention. The laserphaco probe works with a concentrated beam of light that breaks up and destroys the cataract. In the following years, she improved the invention and received three more patents: a method for breaking down and removing cataracts (number 5,843,071), in 1998; another laser product used for surgery on cataract lenses (number 5,919,186), in 1999; and an ultrasound method for the breaking and removing of cataracts (number 6,083,192), in 2000. She has also received patents in Europe, Japan, and Canada.

Dr. Bath is a professor emeritus and was nominated to the National Inventors Hall of Fame by the American Intellectual Property Law Association. After retiring from UCLA in 1993, she continued to promote vision care outreach, especially for the underprivileged.

IMPACT

As the first African American woman to receive a patent for a medical device, Bath is a role model for African

Americans, women, and other minorities. Her laser cataract surgery method has been used throughout the world, including India, Italy, and Germany. Bath's advocacy work with organizations such as the American Institute for the Prevention of Blindness was groundbreaking. Even after retirement, she has maintained a busy schedule, giving speeches to young people, promoting community ophthalmology, and traveling around the world doing surgery. It is her deepest wish to be able to eventually eliminate blindness. She has also promoted telemedicine, the use of electronic communications to deliver medical services to remote regions where medical care is limited or unavailable.

—*Theresa L. Stowell*

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See also: Louis Braille; Charles Richard Drew; Rangaswamy Srinivasan.

ANDREW JACKSON BEARD

American engineer

Beard's major invention was the automatic railroad car coupler, which dramatically improved the speed and safety for joining railroad cars. He also patented a rotary steam engine and an improved plow.

Born: March 29, 1849; Woodland, near Mount Pinson, Jefferson County, Alabama
Died: May 10, 1921; Birmingham, Alabama
Primary fields: Agriculture; railway engineering
Primary inventions: Jenny coupler; rotary steam engine

Early Life

Andrew Jackson Beard was born in 1849 as a slave on a plantation in Woodland, Alabama. His parents, a slave couple, chose the Beard surname from the owner of the plantation. Andrew had no formal education during childhood or at any other time during his life. Consequently, he could neither read nor write. Learning took place through interaction with others. By the time the fifteen-year-old Andrew became a free man, he had already developed skills in agriculture, carpentry, and blacksmithing. He chose to remain on the Beard farm until 1868, eking out a living as a sharecropper. He was able to accumulate enough assets to purchase an eighty-acre farm near Center Point, Alabama. There Andrew and his wife, Edie, raised three sons. He also raised the three sons and daughter of Hattie Horton, one of his sharecropper tenants, and gave them his surname.

Although Beard was proud of owning his own farm, farming became less and less appealing to him. His epiphany came in 1872, after an arduous three-week trip by oxcart to Montgomery. After that trip, Beard built a flour mill and a church (which also served as a school) on his land for his tenant farmers. Although Beard was illiterate, he had a great respect for education.

Beard's flour mill, located in Hardwicks, Alabama, ran smoothly and generated capital, but his mind began to drift to other projects. He began experimenting with designs for an improved plow, and he registered a patent for it in 1881. Another improved plow was patented in 1887. Selling his rights to the patents for nearly $10,000, Beard invested the money into a real estate business. Within a few years, his capital accumulation was $30,000. Once again, Beard's creative energies were channeled in other directions.

LIFE'S WORK

During the early 1890's, Beard became an employee of the Alabama and Chattanooga Railroad (which grew to become the Georgia Pacific and Southern Railway system). He became obsessed with designing a rotary steam engine that would be safer, more efficient, and more economical than the conventional steam engines of his time. Exploding steam engines were a common cause of injury or death, but Beard's rotary engine was not subject to explosion because of its more even distribution of internal pressure. His venture was closely supported by Melville Drennen, who served two terms as mayor of Birmingham. In July, 1892, Beard was granted a patent for the rotary engine by the U.S. Patent Office. Few would have predicted that a former slave, lacking basic literary skills and any sort of structured education, and operating in a deeply racist society, could have achieved so much. He was not only a financial success in several different careers but also a creative genius as an inventor. Although by the age of forty-three Beard had achieved much, his greatest invention was yet to come.

While working on his rotary steam engine, Beard also became intrigued with the problem of joining railroad cars together. Often, railroad yard workers were mutilated or killed while attempting the dangerous operation of dropping a pin at exactly the right moment into a receiver hole of a railroad car in motion. If the worker did not move away from the cars fast enough, he could be crushed. It was Beard's dream to remove the human element from the process and design a system based on the automatic coupling of cars. Beard worked at home tinkering on a safe and efficient means of coupling cars. He was not trained in either engineering or metalworking, so the venture must have seemed overly ambitious to observers. What he designed by 1897 was a system in which horizontal jaws placed at each end of a railroad car engage each other merely by bumping. On November 23, 1897, he received a patent for an automatic coupler. His application was signed with the characteristic *X*, witnessed by two observers.

To attract investors, Beard built a wooden model of the "Jenny coupler," which was displayed at a convention of the Master Car Builders' Association in Atlantic City, New Jersey. Based on the potential of his invention, Beard was made an honorary member of that association. This was a great honor for an uneducated former slave. The distinction also made it possible to attract several Birmingham investors and market his invention. He founded the Beard Automatic Coupler Company and registered four additional patents for improvements to the coupler between 1899 and 1904. Ultimately,

THE JENNY COUPLER

While much railroad technology advanced during the nineteenth century, some remained primitive, including the link-and-pin method used to link freight cars and passenger cars together. To accomplish linkage between cars, a switchman had to stand between the cars as they came together and drop a coupling link into a slot. To achieve this, the brakeman had to signal the engineer to back up into exactly the right position. Timing errors of even a few seconds could be fatal. As the number of railroad cars attached to a train became longer, visual contact in the operation became more difficult to maintain. The result was an ever-increasing loss of limbs and lives. Moreover, coupling pins suffered metal fatigue or were uneven in size and frequently broke. In fact, there was no standard design for a coupling pin, and train crews wasted valuable time trying to match pins and links. Also wasted were money and lives, since coupling-pin failure was a common cause of railroad accidents.

The knuckle coupler was invented by Eli H. Janney in 1873 and provided some relief for link-and-pin coupling problems. However, it was only used after 1888 in freight cars carrying heavy loads and had several drawbacks, including the all-too-frequent need to manually align cars after linkage failures. Hundreds of other coupling devices were patented after Janney's, but none proved efficient or appealing.

Andrew Jackson Beard's "Jenny coupler," patented on November 23, 1897, eliminated the need for workers to be used in the coupler process by having two horizontal jaws attached to the cars that locked together automatically. Because of its reliability and reasonable cost, Beard's invention gained rapid acceptance. In 1893, Congress passed the Railroad Safety Appliance Act, which took effect in 1900, making it unlawful to operate railroad cars that did not have automatic couplers. During the last year that link-and-pin coupling was legal in the United States, three hundred railroad worker deaths due to coupling accidents were recorded.

he sold the rights to the coupler to a New York company for $50,000. Further royalties made Beard the first African American millionaire in Jefferson County.

Beard's new fortune was heavily invested in real estate. For the African American residents of Birmingham, Beard's accomplishments were a source of pride. Often the mustached, bespectacled, well-dressed inventor could be seen with his fine horse and shiny buggy riding down the streets of Birmingham. However, while Beard's investments were at first successful, the issue of his illiteracy and business mismanagement caused many business failures and near bankruptcy. He continued with his inventions as much as declining health allowed but registered no new patents. In his later years, suffering from arteriosclerosis and virtually paralyzed, he lived with his foster daughter, Mamie, in Woodlawn. He was admitted to the Jefferson County Alms House soon before he died. His funeral was held at Jackson Street Baptist Church, and his remains lie in an unmarked grave in Woodlawn Cemetery.

IMPACT

Beard's well-designed rotary steam engine produced little impact in U.S. locomotive design. Ultimately, only a few rotary engines were constructed by European concerns and were used for limited purposes. His Jenny coupler, however, transformed railroad efficiency and safety for rail yard workers. In 1892 alone, there were 11,000 recorded accidents in the United States involving the coupling of railroad cars. In an age before workers' compensation and other types of worker insurance, crippling or deadly accidents such as those produced by being crushed between two railroad cars were tragedies both for the individual involved and for the family who relied on the worker's income.

In 2006, Beard was inducted into the National Inventors Hall of Fame for his contributions to rail transport coupler design. He is credited with inventing the first automatic railroad car coupler, which dramatically reduced serious injuries to railroad workers. Beard's invention, patented in 1897 and improved in 1899, was identified as a forerunner of automatic couplers used today. Automatic couplers also made possible the use of power air brakes, which had not been successfully used with link-and-pin couplers because of excessive slack in the coupling.

The fact that it has taken over a century for Andrew Jackson Beard to gain national recognition as a major American inventor is a situation that has an impact all its own, indicating that African Americans have made a larger contribution to the development of technology in the United States than has been officially recognized.

—Irwin Halfond

FURTHER READING

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McKinley, Burt. *African-American Inventors*. Portland, Oreg.: National Book Company, 2000. Short studies on black inventors, including Andrew Beard. Includes bibliographic references.

Sullivan, Richard Otha. *African American Inventors*. New York: John Wiley & Sons, 1998. Written for a juvenile audience, this work contains a short biography of Beard.

See also: Peter Cooper; Elijah McCoy; George Mortimer Pullman; George Stephenson; George Westinghouse; Granville T. Woods.

J. GEORG BEDNORZ

German physicist

Bednorz, with Karl Alexander Müller, discovered high-temperature superconductivity in a new class of ceramic materials. Although this discovery did not lead immediately to technological applications, it galvanized scientists around the world to search for new and better superconductors.

Born: May 16, 1950; Neuenkirchen, North-Rhine Westphalia, West Germany (now in Germany)
Also known as: Johannes Georg Bednorz (full name)
Primary field: Physics
Primary invention: High-temperature superconductors

EARLY LIFE

Johannes Georg Bednorz (yoh-HAH-nuhs GEY-awrk BEHD-nawrts) was born in Neuenkirchen, a small town in the West German region of North-Rhine Westphalia. His parents, Anton and Elisabeth Bednorz, came from Silesia. During the convulsions of World War II, his parents along with his sister and two older brothers became separated, and the family was not reunited until 1949, with Georg being born in 1950. Anton got a job as a primary school teacher, and Elisabeth taught piano. His mother tried to interest her youngest son in classical music, but he rebelled, preferring to help his brothers in working on their motorcycle and automobile. After Georg began attending elementary school, a charismatic teacher inspired him to see how music and the arts could foster creativity and community spirit, and at thirteen he studied the violin and later the trumpet, which he played in the school orchestra.

As an adolescent, Georg became so interested in chemistry that he set up a laboratory in the basement of his home, where he conducted experiments. During his high school years, he was more fascinated with chemistry than physics, because his physics teacher stressed theories while his chemistry teacher encouraged him to devise his own experiments. In 1969, he entered the University of Münster, intending to major in chemistry, but he found the introductory chemistry classes large and impersonal, and he eventually discovered a group of crystallographers that functioned more as a family. Since he also enjoyed creating complex crystals and investigating their physical and chemical properties, he switched his major to crystallography.

During the summer of 1972, while still an undergraduate, he spent three months at the IBM Research Laboratory in Rüschlikon, Switzerland, a suburb of Zurich. Here he met such distinguished physicists as Karl Alexander Müller, expanded his knowledge of solid-state chemistry, and deepened his understanding of how to grow crystals. In 1973, he was able to spend six months at this laboratory, when he became interested in perovskites, natural minerals named for the Russian count and scientist L. A. Perovski. The perovskites had a fascinating crystal structure, a central feature of which is a metal atom surrounded by six oxygen atoms in an octahedral array. While at Münster, Bednorz met Mechthild Wennemer, a fellow student who became a close friend.

After graduating from Münster in 1976, Bednorz remained for a year to do research, before he joined the laboratory of solid-state physics at the Swiss Federal Institute of Technology (whose acronym, ETH, derives from its German name) in Zurich. He started work on his doctoral thesis under the joint supervision of Heini Gränicher and Müller. While engaged in his doctoral research, he grew close to Müller because of their mutual interest in perovskites. Wennemer came to ETH to pursue her own doctorate, and in 1978 she and Bednorz were married. After he completed his dissertation on the crystal growth of certain perovskites and an analysis of their electric and magnetic properties, he received his Ph.D. in 1982.

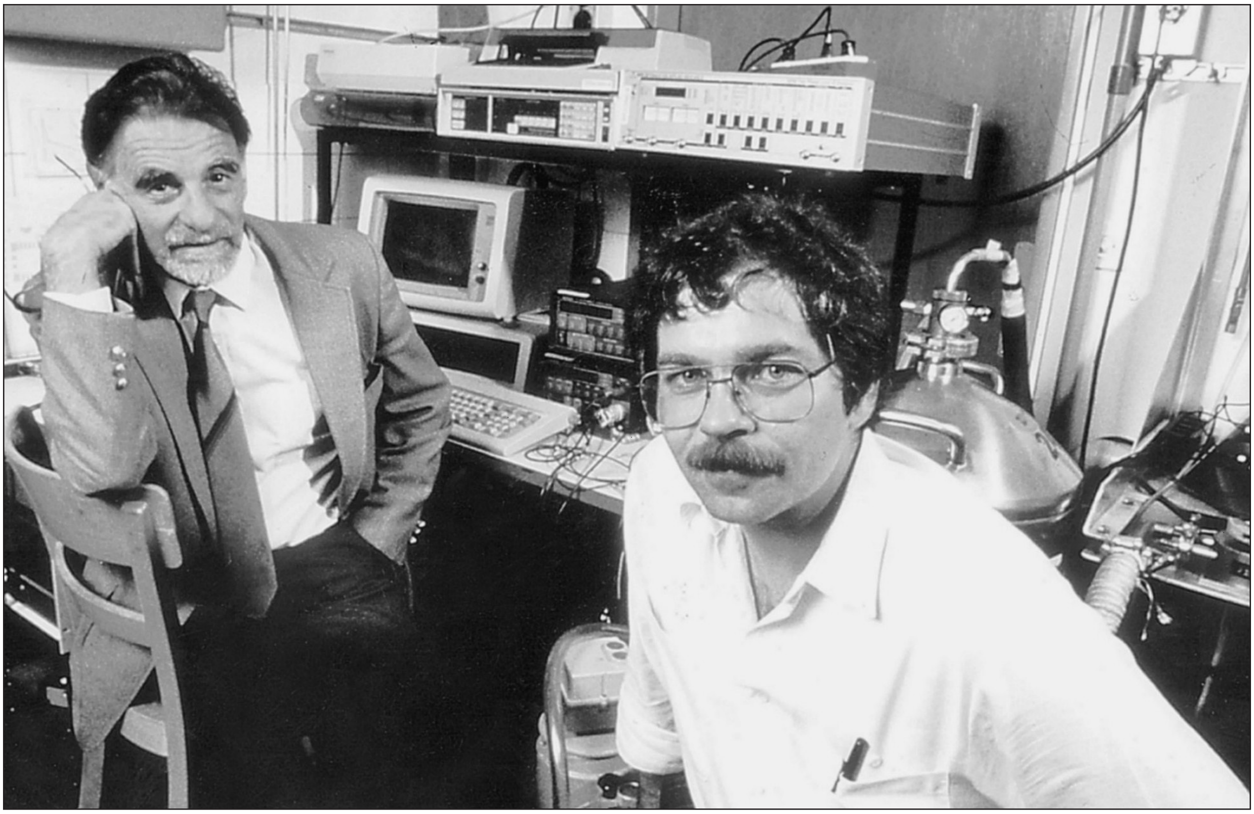
LIFE'S WORK

Once he and his wife settled in Switzerland, Bednorz continued to center his work on the perovskites, especially strontium titanium trioxide and lanthanum aluminum trioxide. When Müller asked him if he would like to investigate whether such oxides conducted electricity with no resistance at temperatures close to absolute zero (this phenomenon is called superconductivity), Bednorz agreed. Unfortunately, Bednorz encountered a series of failures when he made oxides with the metals nickel and copper and tested them for superconductivity.

His luck changed in 1986, when he made and tested a ceramic compound of lanthanum, barium, copper, and oxygen. Within a short time, he was able to show that this perovskite-type oxide superconducted at a temperature as high as 35 kelvins, twelve kelvins higher than the previous record. Because research in this area had become littered with damaged and ruined reputations when claims to have found high-temperature superconductors turned out to be false, Müller and Bednorz were cautious when they submitted their paper to *Zeitschrift für Physik* in April, titling it "Possible High T_c Superconductivity in the Barium-Lanthanum-Copper-Oxygen System." When their paper was published in September, it initially garnered a cautious response. Bednorz has recalled that in his early talks, audiences of scientists were skeptical. It was not until later in 1986 and early in 1987, when magnetic studies of their superconductor verified their claim, that excitement increased and quickly became contagious. Within a very short time, their paper, published without fanfare in a modest journal, gathered over a thousand citations, while scientists all over the world raced to discover more and better high-temperature superconductors.

Although Alfred Nobel had wanted his foundation to recognize recent pivotal discoveries, this had rarely been done, but in the case of Bednorz and Müller it was. In 1987, Müller and Bednorz received the Nobel Prize in Physics for their discovery of high-temperature superconductivity in a new class of materials. Some controversy followed this award, because not one of the scientists who had discovered better high-temperature superconductors than the one of Bednorz and Müller was a corecipient. Members of the Swedish Academy defended their choice by pointing out that the discovery of Bednorz and Müller had led to all the others.

Bednorz continued to do research in this new field that he had helped create, but none of his later discoveries proved to be as significant as his Nobel Prize-winning work. Throughout the remaining years of the twentieth and into the twenty-first century, he received many honors and awards from scientific societies and academic institutions in Europe, America, and Asia, including an honorary doctorate from the University of Silesia, which was especially meaningful to him because of his family's origins. At the IBM Research Laboratory, he studied how the ceramic oxides could be modified to make their use in microelectronic devices effective. For example, he found ways of manipulating certain ceramic oxides so that they might be used as computer memory elements. Unlike his work on the first high-temperature supercon-



J. Georg Bednorz, right, and Karl Alexander Müller won the 1987 Nobel Prize in Physics for synthesizing a new ceramic substance capable of superconductivity at 35 kelvins. (IBM Corporation, AIP Emilio Segrè Visual Archives) ductor, he was now not alone in searching for practical applications based on his discovery. He has become one participant among many seeking ways to develop technologies that will, by making insightful use of high-temperature superconductors, revolutionize all those devices that rely on the transmission of electric current.

IMPACT

The discovery by Bednorz and Müller of the first high-temperature superconductor was remarkable in part because it was totally unexpected, even by those scientists working in the field. Once this discovery had been verified, its impact was revolutionary. It galvanized physicists and chemists all over the world to search for new and better superconductors. With so many researchers engaged in this quest, successes followed, and other ceramic materials with higher and higher transition temperatures began to be discovered. Significantly, Maw-Kuen Wu and his associates showed that a yttrium-barium-copper-oxygen ceramic material manifested zero resistance at temperatures above 90 kelvins (it was called the 1-2-3 superconductor from the relative atomic proportions of its first three elements). Dr. Wu flew from Alabama to Houston, Texas, to perform tests on his new material using the sophisticated instruments of his former dissertation adviser, Paul Chu, thereby confirming his discovery; Chu subsequently became involved in the "race for new superconductors." With his colleagues, Chu created other compounds with increasingly higher transition temperatures, and in 2004 they prepared a compound of mercury, barium, calcium, copper, and oxygen that had a transition temperature to superconductivity in excess of 150 kelvins. The goal of many scientists now is to discover a material that will superconduct at room temperature.

High-temperature superconductors also challenged traditional theories that were satisfactory for low-temperature superconductors. However, despite the efforts of some of the world's best theoreticians, a satisfactory explanation for these new superconductors has yet to gain wide acceptance. Nevertheless, this has not prevented others from trying to discover applications for high-temperature superconductors. Researchers have generally categorized such applications by scale—that is, large and small. In large-scale applications, large currents are involved in such devices as generators, transmission lines, and transformers. In small-scale applications, small currents are involved, such as for analog and digital processing. Hoped-for future applications include high-temperature superconducting maglev trains that will run very efficiently by magnetic levitation. Some predict that improved superconductors will mean better, faster, and less

THE FIRST HIGH-TEMPERATURE SUPERCONDUCTOR

A revolutionary discovery often represents a dramatic transition from a previous state to a radically new one. In the field of superconductivity, not much had changed from 1911, when Dutch physicist Heike Kamerlingh Onnes discovered that mercury completely lost its resistance to electric current when cooled to 4 kelvins. By 1986, despite seventy-five years of research, scientists, using various metals and alloys, had only been able to increase superconductive temperatures to 23 kelvins. The revolutionary discovery of a new class of materials that superconducted at much higher temperatures was due to a confluence of causes. Karl Alexander Müller, after working in the United States, returned to Switzerland convinced that a high-temperature superconductor would have to be an oxide, and he put J. Georg Bednorz to work on such compounds as lanthanum nickel trioxide, a perovskite, but the results were unpromising. Bednorz and Müller moved on to copper-containing compounds, but these, too, gave disappointing results. A turning point occurred in 1985, when Bednorz read about a ceramic compound prepared by French chemists who were only interested in its catalytic properties. Bednorz, on the other hand, thought that this barium-doped lanthanum cuprate with a perovskite structure was a candidate for superconductivity.

Bednorz prepared a sample of the ceramic compounds of lanthanum, barium, copper, and oxygen in a low-temperature oven (had he used elevated temperatures, the resulting sample would have failed to superconduct). In January, 1986, he subjected this material to an electrical test, finding that its resistivity sharply dropped at temperatures as high as 35 kelvins. Preliminary evidence indicated that Bednorz and Müller had found a new superconductor with an unexpectedly high transition point. In April, 1986, they submitted their results for publication, and their paper appeared in September. Later in 1986, magnetic measurements in their own laboratory (with a new magnetometer) and in Tokyo confirmed their discovery, precipitating an avalanche of discoveries of many new superconductors with higher and higher transition temperatures. The importance of their work was recognized by a Nobel Prize in Physics and many other awards. They also had the pleasure of witnessing the explosion of interest and many applications of high-temperature superconductivity that their original discovery had started.

expensive computers. The euphoria that characterized the early history of these superconductors has largely dissipated, replaced by a realization of the difficulties in creating such practical devices as wires from brittle ceramic materials. On the other hand, commercial products with ceramic superconductors are already on the market, and particle accelerators are making use of these superconductors. Judging by the new journals that have appeared, new discoveries continue to be made and new patents applied for and granted. Bednorz, for one, has predicted a bright future for these superconductors in the twenty-first century.

—*Robert J. Paradowski*

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See also: Heike Kamerlingh Onnes; Karl Alexander Müller.

SEMI JOSEPH BEGUN

German American engineer

Begun made important contributions in the field of magnetic recording with his development of tape recorders. He was also one of the early researchers in telecommunications and underwater acoustics.

Born: December 2, 1905; Danzig, Germany (now Gdańsk, Poland)
Died: January 5, 1995; Cleveland Heights, Ohio
Primary fields: Electronics and electrical engineering; military technology and weaponry
Primary invention: Mail-a-Voice recorder

Early Life

Semi Joseph Begun (SEH-mee JOH-sehf BEH-guhn) was born in Danzig, Germany (now Gdańsk, Poland), on December 2, 1905. He studied at the Berlin Institute of Technology and graduated in 1929 with a master of science degree in communications engineering. He did his graduate work at the Berlin Technical Institute in Charlottenburg. There he developed an interest in magnetic recording and wrote a doctoral thesis titled "Magnetic Recording." Later, he also published a book with the same title. After graduating in 1933 with a doctorate in electrical engineering, Begun secured a position with the European division of International Telephone and Telegraph, which operated in Germany as Lorenz AG. He was soon promoted to the position of chief engineer. While working for Lorenz, Begun built the first tape recorder—a dictating machine that used wire for magnetic recording. This tape recorder enjoyed considerable popularity in Europe during the 1930's. Begun also developed the first steel tape recorder for mobile radio broadcasting, the Stahlton-Bandmaschine, which was used by the German Broadcasting System.

LIFE'S WORK

In 1935, Begun emigrated to the United States, where he found that broadcasting companies lacked any interest in his magnetic recording. While continuing to work with magnetic recording on his own, he accepted a position with Guided Radio Corporation. There he developed communication systems for ships. These systems were used to direct passengers to lifeboats in cases of fire or other disasters. Begun's system worked so well that it was adopted by the U.S. Navy. In 1937, Begun left Guided Radio and founded Acoustic Consultants. While involved in this consulting firm, he invented the Sound Mirror, the first tape recorder sold commercially to the public in the United States.

Begun's inventions attracted the attention of the Brush Development Company, located in Cleveland, Ohio. In 1938, he accepted a position in the company's research and development department. When the United States entered World War II in 1941, Begun contributed to the war effort by producing improved magnetic recorders for use in military aircraft. He also invented underwater acoustic sensors with piezoelectric crystals, as well as torpedoes equipped with sonar homing devices.

As a member of the National Defense Research Committee (NDRC), Begun worked to promote research in magnetic recording. During the war, there was a shortage of facilities producing the diamond dies needed to pull ferromagnetic steel into wire, which was used in wire recorders. The NDRC gave Begun a contract to research and develop a substitute for the steel wire used in the military recorders. Begun received a Presidential Certificate of Merit for his work as a member of the NDRC. The award was presented to him by President Harry S. Truman.

THE MAIL-A-VOICE RECORDER

While working for the Brush Development Company, Semi Joseph Begun developed an innovative concept in sound recording, resulting in his Mail-a-Voice recorder. The Brush Development Company manufactured and marketed Begun's invention. The recorder resembled a record player but was equipped with special features and used a special recording medium instead of the wire or tape normally used. The machine was equipped with a record/reproduce selector switch, an erase button for eliminating unwanted parts of a recording, and a pickup arm with special features, in addition to the standard power switch, volume control, and toggle switch for controlling the operation of the turntable. It also had a foot pedal control used to start and stop the turntable and a crystal transducer that functioned as a microphone or receiver in accord with the setting of the record/reproduce selector switch. The pickup arm had a magnetic record/reproduce head and an index and a tuner. The index positioned the magnetic head at any desired point on the recording. The tuner was used to accurately align the magnetic head with the sound track of the recording blank.

The Mail-a-Voice recorder used powder-coated paper disks for recording. Both sides of these disks could be used for recording. The disks were flat and 9 inches in diameter. The sound track was a spiral that ran from an inner five-inch diameter to the outer edge of the disk. The recording track, with a width of 0.014 inch, was closely spaced; the spiral's pitch was 0.025 inch. Yet the recording possessed good clarity with no appreciable cross talk. A tracking disk made the magnetic record/reproduce head in the pickup arm move in a spiral motion outward across the recording blank, magnetizing a track on it. The disk could be folded and mailed in a standard envelope just like a letter.

Designed to execute all of its functions with a minimum of tubes, the Mail-a-Voice recorder used only two double triode tubes. The machine used alternating-current biasing to make recordings but used direct-current saturation of the recording medium to erase previously recorded disks. The erasing was accomplished by holding a permanent magnet on the disk during several revolutions of the turntable.

At the time of its production, the Mail-a-Voice recorder had the simplest and most inexpensive mechanical and electrical design of any commercially produced magnetic recorder. The Brush Development Company manufactured two models of the Mail-a-Voice recorder. One model was principally suited for dictation, the other was meant for use in correspondence. Unlike the latter device, the dictation model was equipped with a solenoid that enabled the user to stop the turntable almost immediately with the foot pedal.

The Mail-a-Voice recorder provided a rapid, easy, and efficient means of sending voice messages. By using a powder-coated paper disk as a recording medium, Begun pioneered the way for the eventual development of the floppy disk.

In 1943, the Brush Development Company appointed Begun vice president of research. He continued his work in recording media and magnetic recording. He developed and demonstrated the first video recording head. He also invented the Mail-a-Voice recorder, composed of a recording/playback machine and powder-coated disks, which were forerunners of the floppy disk. Recording could be done on both sides of the disk. In his position, Begun was instrumental in the negotiation of a sourcing agreement for magnetic tape with the Minnesota Mining and Manufacturing Company (3M). This agreement resulted in a product line that earned $1 billion for 3M. In 1949, Begun wrote the first textbook on the subject of magnetic recording.

In 1952, the Brush Development Company merged with the Cleveland Graphite Bronze Company and became the Clevite Corporation. Begun served as a member of the new company's board of directors. In 1968, Clevite merged with Gould-National Battery to form the Gould Corporation. Begun was the main negotiator for Clevite in the merger. He became vice president of technology for Gould and served on the company's board of directors. In 1969, while working for Gould, he founded Science Management, Inc. (SMI), which provided investment groups and other clients with evaluations of high-technology products and appraisals of management ability of the new companies making the products. In 1971, Begun retired from Gould and founded yet another company, Auctor Associates. This company also provided consultation on high-technology products. The company enjoyed immediate success and served clients in Pittsburgh and Chicago as well as Cleveland.

Begun received numerous honors and awards for his research and development in the electroacoustics field. He received fifty patents during his career. In 1956, he was awarded the Emil Berliner Award by the Audio Engineering Society. In 1960, the society gave him the John H. Potts Medal. In 1993, he was inducted into the Ohio Science, Technology and Industry Hall of Fame. He was also a fellow of the Institute of Electrical and Electronics Engineers (IEEE) and a member of the Audio Engineering Society (AES).

In addition to being an inquisitive and competent researcher, Begun was involved with social concerns. He was particularly alarmed by the ever-increasing violence in American society. In an effort to effect change, he and his wife founded the Society for the Prevention of Violence and Aggression in Children. They also created the Begun Institute for Studies of Violence and Aggression at John Carroll University in Cleveland. Begun died at his home in Cleveland Heights on January 5, 1995. His collected papers are housed at the Smithsonian Institution in the National Museum of American History.

IMPACT

Begun was one of the most productive pioneers in research in the areas of magnetic recording, underwater acoustics, and telecommunications. While working in Germany, he developed the Dailygraph, and then the Stahlton-Bandmaschine. The latter was a major advance in mobile radio broadcasting. After emigrating to the United States, he developed a communication system for use on ships. His system contributed to the saving of innumerable lives in disasters at sea, as the system enabled ship crew members to direct passengers to safety.

With the invention of his Sound Mirror, Begun introduced the tape recorder to the American public. He was instrumental in the development of the sound recording industry in the United States. During World War II, Begun was instrumental in developing technology for the military. As a result of his research, military aircraft were equipped with magnetic recorders, and the Navy was supplied with underwater acoustic sensors and torpedoes equipped with sonar homing devices.

—*Shawncey Webb*

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See also: Emile Berliner; Marvin Camras.

GEORG VON BÉKÉSY

Hungarian American biophysicist

Békésy won the 1961 Nobel Prize in Physiology or Medicine for his discoveries about the mechanics and physiology of hearing, which were seen as a benefit to the deaf.

Born: June 3, 1899; Budapest, Hungary
Died: June 13, 1972; Honolulu, Hawaii
Also known as: George Bekesy; György Malmö
Primary fields: Biology; medicine and medical technology; physics
Primary inventions: Modeling of middle and inner ear; audiometer

EARLY LIFE

Georg von Békésy (GAY-ohrg fon BAY-kay-shee) was the son of Alexander von Békésy, a diplomat in the service of the Austro-Hungarian Empire, and his wife, Paula, née Mazaly. His father's career meant that the family moved frequently and traveled much throughout central and eastern Europe. Besides Budapest, the young Békésy lived in Munich, Germany; Constantinople (now Istanbul), Turkey; and Zurich, Switzerland.

He studied the piano, not only becoming an accomplished player but also developing early the fine acoustic sense that would later be important in his research. Yet he preferred the contemplation of sculpture and other three-dimensional art forms. By the time he was in his mid-teens, he had already become a serious collector of art and would eventually become a self-taught expert in art history.

Békésy completed his secondary education in Zurich in 1916 and passed the Swiss *Maturitäsprüfung* (qualifying examination for higher education). With the defeat and dissolution of Austria-Hungary, the family fortune was at a low ebb at the end of World War I. Despite having to serve in the Hungarian army from 1918 to 1920, Békésy attended the University of Bern, Switzerland, from 1916 to 1920, receiving his bachelor of science degree in chemistry. He studied physics under Károly Tangl at the University of Budapest (now Semmelweis University) from 1920 to 1923, earning his Ph.D. with a dissertation on fluid dynamics and molecular weight.

Georg von Békésy. (©The Nobel Foundation)

LIFE'S WORK

In 1923, the national government hired Békésy in Budapest as a researcher for the Hungarian Postal, Telephone, and Telegraph System. Assigned to investigate why the quality of telephone sound was so poor, he learned that most of this distortion was caused by inadequate earpieces on the receivers. Accordingly, he then began studying the mechanics of the human ear in order to find ways in which these receivers might be improved by making them more compatible with natural processes.

Békésy's basic research led to his creation of working models of various parts of the ear and his invention of several pieces of equipment. He did much of the actual physical labor on these devices himself, using not only common tools such as saws, drills, and files, but also many of his own design. With the assistance of the University of Budapest Faculty of Medicine, he also used cadaver heads and skulls in his research. He would glue mirrors to eardrums to investigate tympanic response to different vibrations and would drill holes in skulls to test cranial resonance. With the freedom to conduct his research however he saw fit, he spent much time in autopsy rooms, morgues, metalworking shops, electrical shops, and hospital wards, as well as his own laboratory.

Except for supplementary employment as a laboratory consultant for the Siemens and Halske Company in Berlin (1926-1927), as a lecturer in physics at the University of Budapest (1932-1934), and as a professor of experimental physics (1939-1946), Békésy stayed with the postal, telephone, and telegraph service until 1946. He and his work were relatively undisturbed during World War II, but with the advent of the communist regime, he felt that he had to emigrate. Because he had neither wife nor children, leaving Hungary was not the problem for him that it sometimes was for those with families. From 1946 to 1947, he worked in Stockholm, Sweden, as a visiting researcher at the Karolinska Institute. While in Sweden, he invented a pure-tone audiometer that patients themselves could control to measure the sensitivity of their own hearing.

In 1947, Békésy came to the United States to accept an appointment in the Psycho-Acoustic Laboratory of Harvard University, which in 1949 promoted him to senior research fellow in psychophysics. At Harvard, he concentrated on improving his mechanical models of the inner and middle ears. His model cochlea in particular became an important instrument for his further research. While at Harvard, he became a naturalized U.S. citizen.

Békésy stayed at Harvard until 1966, when, soon to face Harvard's mandatory retirement age, he moved to the University of Hawaii, which, with funding from the Hawaiian Telephone Company, had promised to build and equip a special laboratory to his specifications. As

MODELING THE INNER AND MIDDLE EAR

Before Georg von Békésy began his research into the mechanics of hearing, the prevailing view of this process was that of Hermann von Helmholtz, who in the 1860's had determined the interrelated functions of the tympanic membrane and the three bones of the middle ear. Helmholtz also discovered the importance of the basilar membrane in the inner ear for hearing, but contemporary techniques did not allow him or other late nineteenth century researchers, such as Italian anatomist Alfonso Corti, to work out the further details of the hearing process. In the 1920's, the purpose of the inner ear remained poorly understood. Part of the problem was the delicacy of the cochlea, which prevented both dissection and close study.

By 1928, Békésy had succeeded in dissecting the ear so that its auditory functions could be studied. He used a low-power microscope on a fresh cadaver under water. With very small mirrors and scissors of his own design, and by performing this complicated postmortem surgery very quickly, he was able to observe wave motion in the cochlea before the inevitable deterioration or damage to the organ made this study impossible. He made the sound waves visible to his microscope by sprinkling silver dust or some other reflective particles on the basilar membrane, then observing the vibrating membrane under an intense stroboscopic light.

The basilar membrane divides the median and tympanic canals within the cochlea. Békésy's new techniques allowed him to discover that as this membrane vibrates it stimulates the hair cells of the adjacent organ of Corti, whose motion is detected by the spiral ganglion of the eighth cranial nerve, the acoustic nerve, which then transmits these impulses to the brain so that hearing can occur. He was also able to correlate various types, amplitudes, and locations of waves along the basilar membrane with the transmission of various aspects of sound, such as pitch, volume, and tone. For example, the basilar waves of high frequencies peak near the entrance to the cochlea, while those of low frequencies peak deeper inside.

Békésy's results from these dissections gave him the knowledge to build functional models of the cochlea that would aid in his further study without the need for studying more cadavers. The most useful of these models, constructed while he was at Harvard University, consisted of a sealed, thirty-centimeter plastic tube filled with water. He would lay his bare forearm along the length of the tube, then introduce sounds at one end of it. Because he could feel the vibrations from each of these sounds each at a different place on his forearm, the nerves in his forearm thus became a substitute for the basilar membrane.

professor of sensory sciences, he investigated all five senses and their interrelations. He remained active in this laboratory until his death. The Békésy Laboratory of Neurobiology remains a major component of the Pacific Biosciences Research Center of the University of Hawaii at Manoa.

Throughout his life, Békésy chose the solitary enjoyment of libraries, museums, and laboratories rather than outdoor or social pursuits. Although he was never gregarious, he was not a typical intellectual recluse. He was friendly, charming, generous, and well-liked wherever he went. He donated his extensive art collection to the Nobel Foundation, his personal and scientific papers, photographs, movies, sound recordings, and other memorabilia from 1928 to 1972 to the Library of Congress, and his art books to the University of Hawaii.

IMPACT

The lifelong center of Békésy's research was the human cochlea, the portion of the inner ear where vibrations are transformed into impulses that the brain can interpret as sound. His Nobel Prize in 1961 was awarded "for his discoveries of the physical mechanism of stimulation within the cochlea," but that was not the extent of his scientific achievement. No problem concerned with hearing was uninteresting to him. Carl Gustaf Bernhard's presentation speech for Békésy's Nobel Prize cited a paper in which Békésy determined the properties of the ear that enable foghorns to be heard far out to sea, but not close by.

Even though he was not a medical professional, and indeed distrusted medicine, his discoveries in physics, physiology, and biomechanics had profound effects on surgery and the clinical sciences of audiology, otolaryngology, neurology, and hearing aid design. Throughout his career, his research involved all aspects of ear physiology and, especially while at Harvard and Hawaii, the physiology of all the senses. Building models and refining instrumentation and techniques was always an integral part of his quest to understand sensory processes.

Besides the Nobel Prize, he also won the 1931 Denker Prize in Otology, the 1937 Leibniz Medal of the German Academy of Sciences, Groningen University's 1939 Guyot Prize for Speech and Otology, the 1950 Shambaugh Prize in Otology, the 1955 Howard Crosby Warren Medal of the Society of Experimental Psychologists, the 1957 American Otological Society Gold Medal, the 1961 Acoustical Society of America Gold Medal, and many other awards. In 1984, the Acoustical Society of America established the Georg von Békésy Medal for excellence in psychological or physiological acoustics. The Hungarian Ministry of Education offers the Békésy György Postdoctoral Research Fellowship.

—*Eric v.d. Luft*

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See also: Alexander Graham Bell; Hermann von Helmholtz; Miller Reese Hutchison.

ALEXANDER GRAHAM BELL

Scottish scientist and engineer

Bell was a prolific inventor and renowned teacher of the deaf, but he is best known for his invention of the telephone. What began as a crude prototype quickly became a useful tool that revolutionized communications.

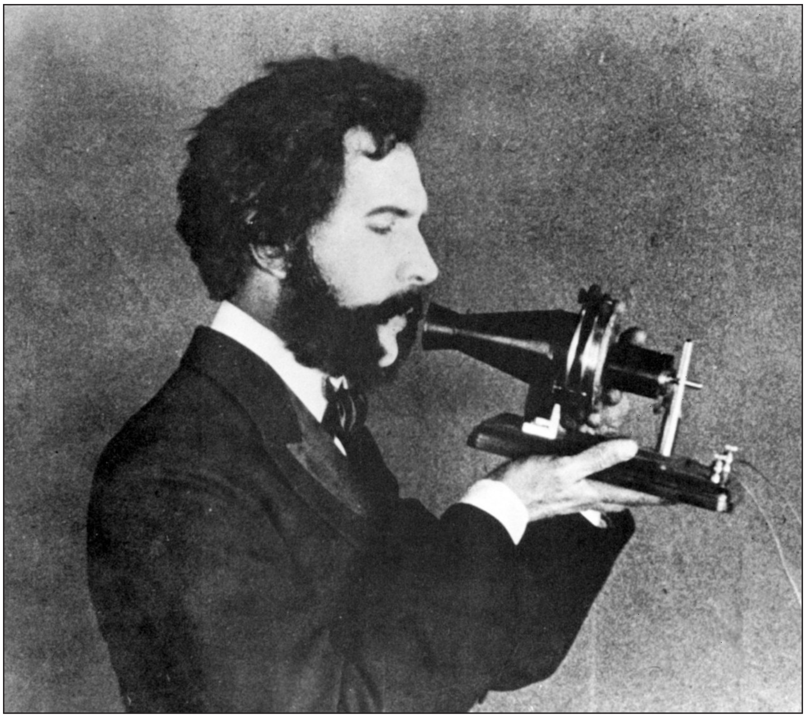
Born: March 3, 1847; Edinburgh, Scotland
Died: August 2, 1922; Baddeck, Nova Scotia, Canada
Primary fields: Communications; electronics and electrical engineering
Primary invention: Telephone

EARLY LIFE

Alexander Graham Bell was born to Alexander Melville and Eliza Grace Bell in Edinburgh, Scotland, in 1847. His father, grandfather, and uncle were elocutionists. Bell's father had invented Visible Speech, a system that uses written symbols to teach the deaf how to articulate words. Bell demonstrated his inventiveness at the age of twelve, when he built a wheat-dehusking device for his neighbor, who used it for a number of years. Together with his brother, Bell built an automaton head that could "speak" a few words. Bell attended Edinburgh's Royal High School for two years and left at the age of fifteen. At sixteen, he secured a job as a pupil-teacher of elocution and music. He studied at Edinburgh University in 1864 and later at University College in London.

After his two brothers died from tuberculosis, Bell moved with his family to London and then to Brantford, Ontario, Canada, in 1870. At the Six Nations Reserve, he learned the Mohawk language and translated its vocabulary into Visible Speech symbols. For his work, he was awarded the title of honorary chief. In 1871, Bell provided an in-service program for instructors of the deaf at the Boston School for Deaf Mutes (now the Horace Mann School for the Deaf and Hard of Hearing) in Boston, Massachusetts. The program was repeated at the American Asylum for Deaf-Mutes in Hartford and the Clarke School for the Deaf in Northampton. The next year, Bell opened a school for deaf pupils (among them Helen Keller) in Boston. Named the Vocal Physiology and Mechanics of Speech, the first class had thirty students. He became a professor of vocal physiology and elocution at the Boston University School of Oratory in 1873.

Though he was busy during the day, Bell stayed up late every night doing research in sound, attempting to find a way to transmit musical notes and articulate speech. (In his late teens, he had begun work on the transmission of sound using tuning forks. He was greatly influenced by the German physicist Hermann von Helmholtz, who had conveyed vowel sounds using a tuning fork.) The device Bell worked on was called a harmonic (or musical) telegraph, and he tried to build one that could send several messages at once through a single wire. He thought he could send multiple messages by varying their musical pitch. When his experiments led nowhere, he decided to concentrate on research and spend less time on his private practice. He had been suffering from severe headaches, and his health deterio-



Alexander Graham Bell speaking into his prototype telephone in 1876. (The Granger Collection, New York)

THE PROTOTYPE TELEPHONE

The first telephone that Thomas A. Watson built for Alexander Graham Bell used a transmitter with an acid-water mixture. The telephone consisted of a funnel, a diaphragm, a cup, and a receiver. A wire attached to the diaphragm floated in the liquid in the cup. Another wire attached the cup to the receiver. Speaking into the funnel caused the diaphragm at the bottom to move, which in turn moved the wire in the liquid. When the wire moved, it changed the resistance within the liquid. The varying current sent to the receiver caused the diaphragm to vibrate and produce sound.

Although this crude prototype proved that speech could be transmitted electrically, the device was not practical, and Bell did not use it in his public demonstrations. Instead, he used a prototype that used an electromagnet instead of liquid. The design consisted of a transmitter, receiver, and magnet. Attached to the transmitter and receiver was a metal diaphragm. Speaking into the transmitter caused the diaphragm to move and the phone line to transfer this motion to the receiver. When the diaphragm of the receiver vibrated, sound was produced. The drawback to this design was that it used a single microphone: The user spoke into it and then put it to the ear to listen. There was also a time lapse in the transmission. Thomas Alva Edison later improved the telephone by dividing it into two pieces: a movable earpiece and a stationary speaking tube. Another drawback to this prototype telephone was that it was voice-powered: The user had to shout into the transmitter to be heard as well as to overcome noise and distortions. Other inventors, notably Francis Blake, Jr., contributed to improving the telephone. Blake, like Edison, invented a transmitter that improved the sound clarity of the device.

rated. He retained only two students—George Sanders, deaf from birth, and Mabel Hubbard, who had lost her hearing because of scarlet fever at age five. Sanders's father provided Bell with free room and board and made arrangements for his son to live near Bell's boarding house. Ten years younger than Bell, Hubbard became the object of his affection.

LIFE'S WORK

During the summer of 1874, Bell made experiments on a teaching aid for the deaf called the phonoautograph, which was made from a dead man's ear. Speaking into this device caused the ear membrane to vibrate and move a lever, which wrote a wavelike pattern of speech on smoked glass. Bell thought it might be possible to use a membrane to vary an electric current in intensity with the spoken word. He also thought that multiple metal reeds (or springs) tuned to different frequencies could be used to convert the electric current back into sound. When Bell revealed his secret work on his harmonic telegraph to his two students' parents—Gardiner Greene Hubbard, a lawyer and the president of the Clarke School for the Deaf, and Thomas Sanders, a prosperous businessman—both showed interest in funding his research. In February, 1875, Hubbard, Sanders, and Bell signed an agreement that supported Bell financially in return for equal shares from any patent he developed. Anthony Pollok, Hubbard's patent attorney, would handle patent matters. Bell hired Thomas A. Watson, an experienced electrical designer and mechanic, as his assistant. In the following month, Bell met with Joseph Henry, who had pioneered electromagnetism and helped Samuel F. B. Morse with the telegraph. The scientist advised Bell to get the necessary electrical knowledge, drop the work on his harmonic telegraph, and concentrate on transmission of speech by electricity.

In June, 1875, Bell and Watson were working on the harmonic telegraph when he heard a sound come through the receiver. Watson had accidentally plucked one of the reeds. Also, one of the contact screws had been set too tightly, allowing current to run continuously. Bell realized that only one reed, not multiple ones, was needed, and that continuous current was essential for transmission of sound. Watson built the first telephone the next day. Called a "gallows" telephone because of its frame, it had a diaphragm substituted for the reed. It was able to transmit a few odd sounds, but not clear speech. Bell was very much disappointed, and his experimenting slowed through the rest of the year. He spent some time writing a patent application to protect his ideas even though he had not built a working model for his telephone. Fortunately, the U.S. Patent Office at that time did not require that a working model accompany a patent application.

On February 14, 1876, while Bell was in Boston, his patent application was filed by Pollok with the Patent Office. On the same day, Elisha Gray filed his caveat for a telephone using a water transmitter. A professional inventor, Gray, together with Thomas Alva Edison, had been contracted by Western Union to find a way to send multiple messages using only a single line on the telegraph. Who filed first is still a debate, and what happened that day is still a mystery. Bell's patent was eventually challenged by some six hundred lawsuits, five of which went to the Supreme Court. Even the U.S. government wanted to annul Bell's patent based on the grounds of fraud and misrepresentation. Gray's challenge to the patent was based on the rumor that Pollok had access to his caveat and copied the principle of variable resistance and the description of the liquid transmitter onto Bell's application. However, Bell won every case. The Patent Office issued to Bell U.S. Patent number 174,465 on March 7, 1876, for his electric speaking phone. In late 1877, Gray applied for a patent for the same invention, but the Patent Office determined that "his failure to take any action amounting to completion until others had demonstrated the utility of the invention deprives him of the right to have it considered."

Three days after his patent was issued, Bell was experimenting with a transmitter when he succeeded in getting his telephone to work. The liquid that Bell used for the transmitter was a mixture of acid and water. According to legend, when he accidentally spilled some of the liquid on his clothes, he called his assistant for help. Watson heard Bell's words clearly in the next room.

In August, 1876, Bell demonstrated that his telephone could work over long distances. His first message was sent from the telegraph office in Mount Pleasant to Brantford five miles away. Bell introduced his invention to the scientific community and the general public and also at the 1876 Centenary Exhibition in Philadelphia. Pedro II of Brazil ordered one hundred telephones for his country. Bell, Hubbard, and Sanders wanted to sell the patent to Western Union for $100,000, but the company's president declined the offer. (Afterward, he regretted his decision, saying that paying $25 million for the patent would have been a bargain.) In 1877, the Bell Telephone Company was established, and a few days later Bell married Mabel Hubbard. They had four children: two girls, and two boys who died in infancy.

In 1880, the French Academy, representing the French government, presented Bell the Volta Prize of 50,000 francs ($10,000) for his invention. With this money, Bell established the Volta Laboratory in Washington, D.C. Other honors included the Albert Medal from the Royal Society of Arts in London, an honorary Ph.D. from the University of Würzburg (Germany), the Edison Medal from the American Institute of Electrical Engineers, and induction into the Legion of Honor. Named after Bell, the decibel (dB), equal to 0.1 bel (B), is a unit for measuring sound intensity. Also named for him is the IEEE Alexander Graham Bell Medal, established in 1976 to award contributors in the fields of telecommunications.

Bell was issued fourteen patents for the telephone and the telegraph and four patents for the photophone, which transmits speech by light rays. He shared twelve other patents with his collaborators for the phonograph, aerial vehicles, hydroairplanes, and selenium cells. Other inventions included the audiometer, which measures acuity in hearing, and the induction balance, used to locate metal objects in human bodies.

Bell became a naturalized U.S. citizen in 1882. He alternated between two homes—Washington, D.C., and his private estate Beinn Bhreagh ("beautiful mountain" in Gaelic) in Baddeck, Nova Scotia. Bell has been claimed as a "native son" by the United States and Canada. Canada maintains the Alexander Graham Bell National Historic Site in Nova Scotia, the historic Bell Homestead, and the world's first telephone company building. Collections of Bell's documents reside at the U.S. Library of Congress, Manuscript Division, and at the Alexander Graham Bell Institute at Cape Breton University in Nova Scotia.

Bell died of pernicious anemia at his private estate on August 2, 1922, survived by his wife and two daughters.

IMPACT

Improvements to the prototype telephone helped develop it into a successful product. The use of the telephone spread quickly after the first commercial switchboard was set up in New Haven, Connecticut, in 1878. Four years later, 60,000 people owned telephones; the number jumped to 150,000 in 1886. Thanks to Thomas Alva Edison's invention of the carbon microphone, the telephone became a practical long-distance tool. In 1884, the first long-distance line was built, connecting Boston and New York. With the perfection of insulation, 11,000 miles of underground wires were used in New York City by 1889. By the turn of the century, the telephone had become a necessity, connecting people and paving the way for an interconnected world market and future developments in information technology. With 14,000 miles of copper wire strung across the country, the first transcontinental call was made in 1915.

—*Anh Tran*

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See also: Alexander Bain; Georg von Békésy; Emile Berliner; Martin Cooper; Glenn H. Curtiss; Thomas Alva Edison; Elisha Gray; Hermann von Helmholtz; Joseph Henry; Heinrich Hertz; Peter Cooper Hewitt; David Edward Hughes; Miller Reese Hutchison; Bob Kahn; Lewis Howard Latimer; Guglielmo Marconi; Samuel F. B. Morse; John Augustus Roebling; Frank J. Sprague; Alessandro Volta; Eli Whitney.

CARL BENZ

German mechanical engineer and machinist

Benz designed and built the world's first practical horseless carriage, and he was the first to produce the first mass-produced automobile. The Mercedes-Benz automobile is one of his best-known legacies.

Born: November 25, 1844; Karlsruhe, Baden (now in Germany)
Died: April 4, 1929; Ladenburg, Germany
Also known as: Carl Friedrich Benz (full name); Karl Benz
Primary fields: Automotive technology; manufacturing; mechanical engineering
Primary invention: Gasoline-powered automobile

EARLY LIFE

Carl Friedrich Benz (behnts) was born on November 25, 1844, in Karlsruhe, Baden (now in Germany), to Josephine Vaillant and Johann George Benz, an engine driver on the Karlsruhe railway. Carl was two years old when his father was killed in a railway accident. The railway authorities awarded Josephine a small monthly pension. To supplement the meager pension, she took menial jobs.

Despite being impoverished, his mother strove to give her son a good education, and he attended the local grammar school. At the age of nine, after easily passing the entrance exam, Benz started at Karlsruhe Lyceum, a school renowned for its high standard of teaching in the natural sciences. Physics became a passion for him. His mother saved money to provide a small home laboratory for his studies and took in lodgers. Benz repaired clocks and watches in his spare time. He later attended Karlsruhe Polytechnical University under the instruction of Ferdinand Redtenbacher. There, Benz studied locksmithing, eventually focusing on locomotive engineering. In 1860, at the age of fifteen, he matriculated at the University of Karlsruhe, and he graduated in 1864. It was during his time at the university that Benz imagined the vehicle that would become the horseless carriage.

After graduation, Benz began his professional training in Karlsruhe, working at various mechanical engineering jobs for two years before moving to Mannheim to work as a draftsman and designer in a scales factory. In 1868, he began working for Gebrüder Benckiser Eisenwerke und Maschinenfabrik, a bridge-building company in Pforzheim, before going to Vienna to work at an iron construction company.

LIFE'S WORK

In 1871, at age twenty-seven, Benz founded his first company in Mannheim, an iron foundry and mechanical workshop. It was a joint venture with August Ritter, a partnership that proved disastrous within the first year. In 1872, Benz married Bertha Ringer, with whom he had five children: Eugen, Richard, Clara, Thilde, and Ellen.

By 1878, Benz was developing new engines and earning patents. That year, he created a reliable two-stroke engine, and he was issued a patent for this engine in 1879. He also registered a number of other inventions, including the speed regulation system, the carburetor, the clutch, the spark plug, and the water radiator.

Because of his factory's high production costs, the Mannheim banks demanded that Benz's factory be incorporated, and in 1882 it became Gasmotoren-Fabrik Mannheim. In 1883, he left the company, disgruntled that he was barely consulted for technical decisions. That year, he established Benz and Company, producing industrial machines with Max Rose and Friedrich Wilhelm Esslinger, owners of a bicycle repair shop in Mannheim. Benz turned to designing a vehicle with an internal combustion engine. By 1885, he had created the first practical gasoline-powered automobile, the Benz Patent Motorwagen, and was granted a patent in 1886.

By 1890, Benz and Company had grown to fifty employees and expanded to a larger facility. In 1893, Benz designed the Victoria, a two-passenger automobile with double-pivot steering. The following year, the Velo model was improved, and in 1895 Benz created the first truck in history. In 1896, he was granted a patent for the horizontally opposed piston engine.

By the early twentieth century, competition with Daimler-Motoren-Gesellschaft (DMG), which produced Mercedes cars, had become inevitable. It is not certain whether Benz and Gottlieb Daimler knew of each other's accomplishments, as Daimler died in March, 1900. In 1903, Benz retired from his company out of protest when French engineers at the Mannheim plant were hired. These engineers were supposed to help restore the competitiveness of Benz's company.

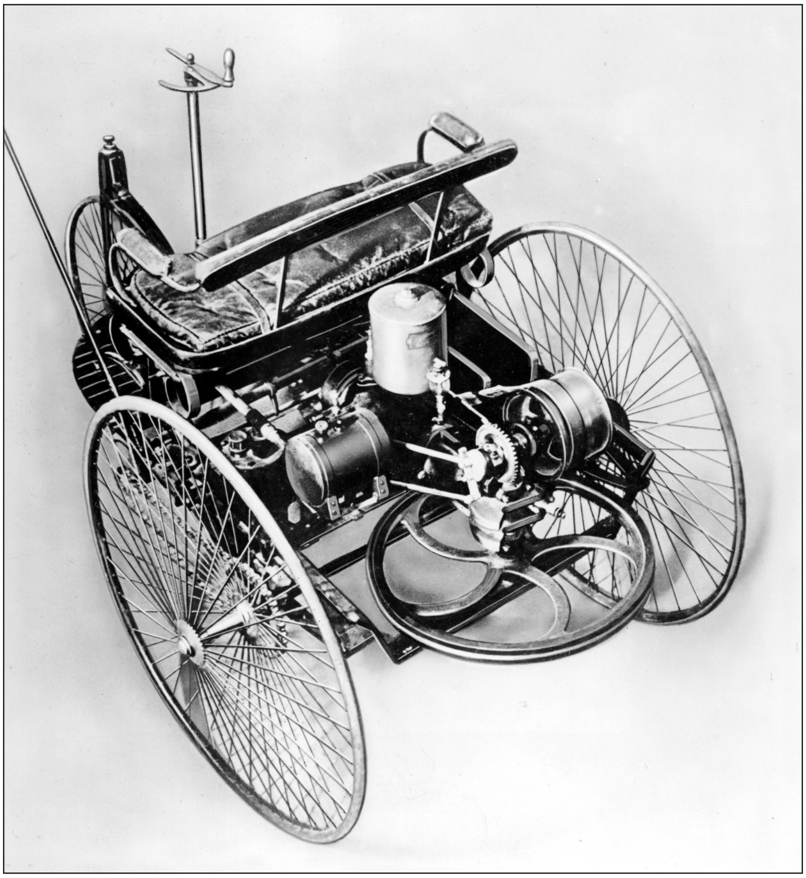
Benz moved his family first to Darmstadt, then to Ladenburg. In 1906, he founded C. Benz Söhne with his son Eugen. They produced automobiles and gas engines but, with the slump in gas engines sales, focused on automobiles. In 1908, Richard, Benz's second son, joined the company. In 1912, Benz liquidated his shares in C. Benz Söhne, leaving his family-held company in Ladenburg to his two sons, but he remained as a director of Benz and Company. On his seventieth birthday, he was awarded an honorary doctorate by his alma mater, the University of Karlsruhe, in his hometown celebration.

After World War I, with the slump in the German economy, both Benz and Company and DMG had sales difficulties. To survive the situation, in 1919 Benz and Company representative Karl Jahn proposed a merger with DMG, but the proposal was rejected in December. The economic situation worsened. In 1924, a mutual agreement was signed for both companies to market their automobiles jointly but to keep their respective brands. On June 28, 1926, Daimler-Benz was formed, and all its automobiles bore the brand name Mercedes-Benz. The new company created its logo: Daimler's three-pointed star, which represented the automaker's ambition to produce engines for land, air, and water, surrounded by the laurels from the Benz logo.

Carl Benz died of bronchial inflammation on April 4, 1929, at his home in Ladenburg. Bertha Benz continued to reside in their home until her death on May 5, 1944. Family members resided there for thirty more years. The Benz home has been designated as the historic headquarters of the Gottlieb Daimler and Karl Benz Foundation.

Impact

A pioneer in the automobile industry, Benz built the world's first commercial automobile powered by an internal combustion engine. In 1885, Benz fitted a scaled-



Carl Benz's two-seater tricycle, the first gasoline-powered automobile, invented in 1885. (Getty Images) down engine to a two-seater tricycle, producing the first gasoline-powered automobile. His vehicle included electric ignition, mechanically operated engine valves, a water-cooled engine, and differential gears—all features found in today's automobiles. After success with his early two-stroke engine, Benz built a four-stroke that achieved great success when installed in a four-wheel vehicle.

In 1893, Benz's Velo model became the world's first mass-produced automobile. His lightweight, self-driven automobiles built to a standardized pattern set the standard for other automakers. With his genius, supported by the business acumen, pure devotion, and persistent optimism of his wife, Bertha, Benz had become the biggest maker of cars in the world by 1900. In 1926, Benz and Daimler merged to produce the famous Mercedes-Benz, a car that continues to stand for quality and excellence to this day.

—*Tel Asiado*

THE GASOLINE-POWERED AUTOMOBILE

Carl Benz, the "father of the automobile," designed his gasoline-powered two-stroke piston engine in 1878 and focused on developing a motorized vehicle while working as a designer and manufacturer of stationary engines. In 1885, Benz designed and built the first commercial automobile in history, the Benz Patent Motorwagen. It was awarded a German patent on July 3, 1886.

Benz's motorcar was the first automobile designed to generate its own power. It was a three-wheeled vehicle with a rear-mounted engine, and power transmitted by means of two roller chains to the rear axle. The first successful tests of the motorcar were carried out in the early summer of 1886. His Model 3 had two horsepower; its maximum speed was approximately ten miles per hour.

A Parisian bicycle manufacturer and engineer by the name of Emile Roger purchased an 1888 Benz and decided to add the automobiles to the line he carried in Paris. Roger became a key sales partner for Benz. The early 1888 version of the motorcar had to be pushed when driving up a steep hill, but this limitation was rectified after Bertha Benz made her famous trip driving one of the prototypes. She suggested to her husband the addition of a low gear for hills.

On August 5, 1888, Bertha began the first long-distance automobile trip to demonstrate the reliability of her husband's motorcar. Bringing along her teenage sons Eugen and Richard, she drove from Mannheim through Heidelberg, Wiesloch, and Durlach, to Pforzheim, where she sent a telegram to her husband notifying him of their arrival. The trip covered 180 kilometers (112 miles).

About twenty-five motorcars were built between 1886 and 1893. By the end of 1892, almost a dozen had been sold, and more were on order. At the turn of the twentieth century, Benz produced more than two thousand motorcars.

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FRIEDRICH BERGIUS

German chemist

Bergius developed a method of converting coal to liquid fuel by high-pressure hydrogenation. He invented a procedure for converting wood into edible carbohydrates, and he perfected a process for manufacturing pure hydrogen gas from water and iron. Synthetic fuels made by the Bergius process were vital to the German war effort in the 1940's.

Born: October 11, 1884; Goldschmieden, near Breslau, Germany (now Wrocław, Poland)
Died: March 30, 1949; Buenos Aires, Argentina
Also known as: Friedrich Karl Rudolf Bergius (full name)
Primary field: Chemistry
Primary invention: Bergius process

EARLY LIFE

Friedrich Bergius (FREE-drihk BEHR-gee-uhs) was born in Goldschmieden, near Breslau, Germany (now Wrocław, Poland), where his father owned a chemical factory. Friedrich became familiar with chemical work at the factory and later worked in a larger plant in Mülheim. At the university, first at Breslau and later at Leipzig, he studied organic chemistry. At the latter institution, he worked under the direction of Arthur Hantzsch (1857-1935).

Having earned his doctorate in 1907 with a thesis on the use of 100 percent sulfuric acid as a solvent, Bergius went to Berlin to do postdoctoral work with Walther Nernst (1864-1941; Nobel Prize, 1920). With Nernst, Bergius did research on hydrogen-nitrogen-ammonia equilibrium, as had Fritz Haber (1868-1934; Nobel Prize, 1918). In Nernst's laboratory, Bergius had his first opportunity to conduct high-pressure reactions. Haber had moved on to Karlsruhe, and Bergius joined him there for a few months to continue his work with high pressures.

In 1909, Bergius joined the Hannover Institute of Technology, where the physical chemistry department was headed by Max Bodenstein (1871-1942). At the institute and in his own private laboratory, Bergius studied the equilibrium of calcium oxide, oxygen gas, and calcium peroxide, and he solved many fundamental problems with high-pressure valves and fittings and stirred reaction vessels. He abandoned work involving high-pressure oxygen after experiencing a serious explosion, but later he was able to patent a method for reacting sodium hydroxide with chlorobenzene to form phenol. This process became an important industrial source of phenol. During this period, Bergius became interested in the geochemical formation of coal and its duplication in the laboratory. This interest led him to the study of coal hydrogenation, leading to a process for making synthetic gasoline and oils, probably his most lasting achievement.

LIFE'S WORK

Petroleum is fractionally distilled in refineries to obtain useful products. The products in greatest demand tend to be those with the lowest boiling points (such as gasoline and kerosene) in which the hydrocarbon chains are fairly short. "Cracking" (a chemical process by which large molecules are broken down into smaller ones) of long-chain hydrocarbons produces more of the desirable products. Bergius studied cracking and found that high-pressure hydrogen in combination with high temperature gave better results than heating alone. Close temperature

Friedrich Bergius. (©The Nobel Foundation) control minimized coke formation, a major drawback of thermal cracking. An apparatus was designed to permit removal of volatile products as hydrogenation occurred. Bergius hydrogenated and cracked many different specimens of heavy oil, obtaining lower-boiling liquids and gases. Plentiful supplies of hydrogen were needed for this research, and Bergius investigated methods for its production.

Carbon (usually coke is used) reacts with steam at high temperature—about 900° Celsius (1,652° Fahrenheit)—to give a mixture (water gas) of carbon monoxide and hydrogen. Modifying this reaction, Bergius tried reacting peat with water at high temperature and high pressure. He obtained carbon dioxide, hydrogen, and a solid residue resembling coal. This "artificial coal" reacted with high-pressure hydrogen to give a mixture of products soluble in organic solvents (such as benzene). Hydrogenation of natural coal gave similar results. A patent was filed in 1913 for the coal hydrogenation process. Artificial coal also resulted from the reaction of high-pressure water and steam on wood. Bergius theorized that coal might have originated in wood from primeval forests being buried and suffering the effects of heat and pressure under the earth.

Bergius engaged in a prolonged period of work to increase the output of his coal hydrogenation process, and he was soon forced to seek additional funds from a group of financiers. World War I had now begun, and Bergius needed to obtain a deferment from military service. His next step was an alliance with the firm Theodore Goldschmidt AG.

In 1915, Bergius began the construction of a new facility at Mannheim-Rheinau, where coal hydrogenation could be done on a larger scale. Because of the war and postwar collapse of the German economy, it took until 1924 to get the plant running, and expenses mounted. Financial problems led Bergius to sell interests in his plant to other interested firms: Shell Oil, Imperial Chemical Industries (ICI) in Britain, and eventually Badische Anilin- und Soda-Fabrik (BASF). The remaining development of coal hydrogenation fell to Carl Bosch at the Leuna plant of Interessen Gemeinschaft Farben (I. G. Farben, a chemical cartel), twenty miles west of Leipzig near Merseburg.

After about 1925, Bergius entered a new phase of work in which he became interested in making food from wood. Cellulose, the major structural material in wood and plants, is composed of long chains of glucose units linked by shared oxygen atoms. Some animals, such as deer, can digest cellulose, breaking the oxygen links and obtaining nourishment from the glucose. Humans cannot digest cellulose, but in a chemical reactor, cellulose can be broken down by strong acids to form sugars. Organic chemist Richard Willstätter (1872-1942) discovered that cellulose could be successfully broken down into sugars by the use of 40 percent hydrochloric acid at room temperature. Others had used sulfuric acid at higher temperatures. Bergius applied the hydrochloric acid method to the solubilization of the cellulose in wood waste, an abundant raw material. The cellulose was broken down in two stages: first to form sugars such as glucose, mannose, xylose, galactose, and fructose in tetrameric form, then after dilution and further heating, to form the monomeric sugars. The glucose, galactose, and mannose were fermentable by yeast to produce ethanol. One metric ton of dried wood yielded 320-338 liters of 95 percent ethanol. The lignin content of the wood precipitated out during the acid treatment and was recovered for use as fuel.

Bergius designed and operated a plant at Mannheim-Rheinau for the implementation of his cellulose process. The economical operation of the process required recovery of the acid by distillation. The hydrochloric acid presented serious corrosion problems in that it attacked most of the common materials of construction; therefore, ceramic parts were used in the still, which operated under vacuum at slightly above room temperature. It was also possible to recover acetic acid as a by-product.

In 1931, Bergius and Carl Bosch shared the Nobel Prize in Chemistry for their achievements in high-pressure chemistry. Bergius was the recipient of many other honors, including an honorary D.Phil. from the University of Heidelberg. After World War II, Bergius lived in Austria and Spain before settling in Argentina, where he served as a technical research adviser to the government from 1946 to 1949. He died in Buenos Aires on March 30, 1949.

IMPACT

Bergius took his coal hydrogenation process to pilot-plant scale at his Mannheim-Rheinau installation. He had demonstrated the process and shown that it could be an important source of synthetic fuels if implemented on a large scale. Further development was done by others at BASF and I. G. Farben, resulting in the opening of a large installation at Leuna in 1927. Improvements were made to the Bergius process at Leuna. Bergius's original single-step process was separated into a liquid-phase hydrogenation step catalyzed by metal sulfides or oxides, and a vapor-phase hydrocracking step. This resulted in better-

PRODUCTION OF LIQUID FUELS BY HYDROGENATION OF COAL

Germany has plentiful deposits of coal, particularly brown coal, or lignite, but very little petroleum. Friedrich Bergius sought to improve on the discoveries of Marcellin Berthelot (1827-1907), who in 1869 reported coal hydrogenation experiments using higher pressures of hydrogen, envisioning an industrial-sized operation. Since different types of coal vary in their suitability for hydrogenation, Bergius tested a multitude of coal samples and determined that soft coal and lignite rather than hard, or anthracite, coal work best for hydrogenation.

The reactions released heat, which needed to be dissipated since excessive temperature produced coke, which resisted hydrogenation. Powdered coal was made into a paste with oil and subjected to hydrogen gas. The oil helped to make the heating more uniform. The reaction produced various hydrocarbons as the hydrogen broke down the complex carbon-atom network in the coal. Bergius designed both rotating and stationary autoclaves to facilitate mixing and temperature control, and he was able to handle batches of four hundred liters. The inefficiency of the batch process led Bergius to develop a continuous process on a larger scale. The paste of powdered coal and oil was preheated and forced into a reactor by a ram, while products were continuously removed. The reactor consisted of a steel cylinder eight meters long and one meter in diameter mounted horizontally. Temperature control was important, and Bergius developed a heat-exchange method involving bathing the reactor in a stream of inert gas at the proper temperature.

The hydrogen needed for the process was available from the action of steam on hot coke (water gas reaction) but needed to be freed of carbon monoxide. Previous workers had done this by cooling the gas mixture enough to liquefy the carbon monoxide. Bergius was able to conduct the water gas reaction at a lower temperature by working at high pressure with a thallium chloride catalyst. Under these conditions, the carbon monoxide was converted to the dioxide, which could be removed by reaction with alkali. Serendipitously, Bergius discovered that the high-temperature water was reacting with the iron parts of the reactor, producing hydrogen gas. This reaction he developed into a method for making large quantities of pure hydrogen-reacting water with iron filings at high temperature and pressure. The by-product iron oxide could be reduced back to iron and reused.

quality fuels. By 1931, Leuna was producing synthetic fuels at the rate of 2.5 million barrels per year. By 1944, Germany had twelve plants and was producing at the rate of 25 million barrels per year, including almost all of the aviation fuel for the Luftwaffe.

Coal hydrogenation was developed in England by the British government and by ICI using Bergius's methods. By 1935, England had a plant that produced gasoline at the rate of 100,000 barrels per year. Synthetic fuels have tended to be more expensive than those derived from petroleum, and interest in them becomes greater when petroleum is expensive or scarce. Coal gasification followed by catalytic reaction of carbon monoxide and hydrogen (Fischer-Tropsch reaction) is an alternative to the Bergius process for liquid fuels. In the early twenty-first century, synthesis of liquid fuels from coal is practiced in many countries, including the United States, South Africa, and the United Kingdom.

The conversion of cellulose to ethanol is a promising renewable source of fuel, and it is a subject of active research in the twenty-first century. Interest, however, centers most on enzymatic processes rather than the acid hydrolysis favored by Bergius.

—*John R. Phillips*

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See also: Carl Bosch; Fritz Haber.

EMILE BERLINER

German American engineer

German immigrant Berliner's fascination with science and audio technology led to improvements in the telephone, the invention of the flat-disc gramophone, and a prototype helicopter.

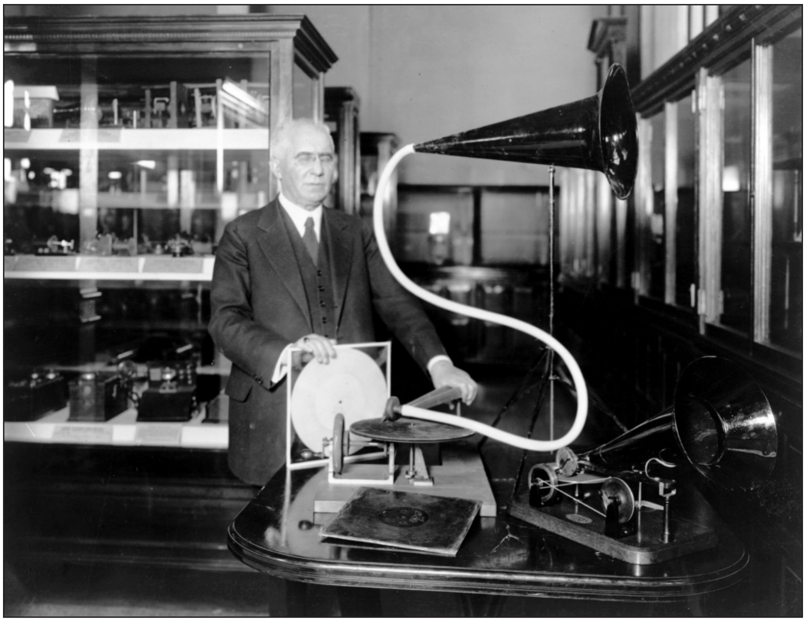
Born: May 20, 1851; Hanover (now in Germany)
Died: August 3, 1929; Washington, D.C.
Primary fields: Acoustical engineering; aeronautics and aerospace technology; communications; music
Primary inventions: Gramophone; record disc; helicopter prototype

EARLY LIFE

Emile Berliner (EH-meel BUHR-lih-nuhr), one of thirteen children, was born in 1851 in Hanover (now in Germany) to Jewish parents. His father, Samuel, was a merchant and scholar, and his mother, Sarah Fridman, was a musician. Berliner's appreciation for music prompted him to take lessons on piano and violin. At age fourteen, Berliner had already graduated from the Samsonschule in Wolfenbüttel, a reputable school of languages and science. In order to lend financial support to the family, he ended his schooling and worked as a printer, then as a clerk in a fabric store. His first invention was an improved loom for weaving cloth.

Berliner immigrated to the United States in 1870, when he accepted a position in a dry goods store in Washington, D.C. After three years, he moved to New York City, working various day jobs as a traveling salesman and dry goods clerk while studying at the Cooper Institute (now known as the Cooper Union, a prestigious fine arts and engineering college in Manhattan) at night.

In 1875, Berliner worked in Constantine Fahlberg's research laboratory, which sparked his interests in inventing and science. A year later, Berliner returned to his position as a clerk in Washington, D.C. During the Centennial Exposition of 1876, Alexander Graham Bell's telephone discovery occupied center stage. Berliner was fascinated with the new invention and decided to pursue the development of his own telephone. He spent long hours at the Cooper Institute library studying electricity and physics. By 1876, Berliner had invented a new telephone transmitter, essentially a carbon microphone, which was patented a year later.



Emile Berliner stands with his flat-disc gramophone, the first of its kind. (Library of Congress)

LIFE'S WORK

The year 1877 was pivotal for Berliner. His transmitter was purchased

THE RECORD DISC

Emile Berliner patented the flat record disc, his production methods, and the gramophone in 1887. Numerous improvements followed in subsequent years. The patent protected Berliner's design of etched grooves of a uniform depth, cut laterally, resulting in clearer sound production, durability, and increased volume compared to Thomas Alva Edison's cylinder recordings.

The gramophones of 1887-1888 recorded on a polished glass plate, later on zinc. The plates were covered with a thin coating of beeswax diluted by benzene. The recording grooves formed tracks that guided the sound box's movement across the record. The sound box holds the gramophone needle in place at about a 60-degree angle with a thumbscrew. The grooves' rigid walls reduce the side-to-side movement of the needle, diminishing wear.

The plate is mounted on a centered, vertical spindle within an etching trough. Both the spindle and the plate revolve together. The stylus (needle), diaphragm, and the mouth tube are attached to a carriage that gravitates toward the center of the plate. A friction wheel on a horizontal shaft on the side of and underneath the plate forces the rotation of the plate. The wheel is attached to a hand crank that extends outside the case. By cranking the handle, the wheel turns the plate.

As the plate revolves, the mouth tube receives the sound, which in turn causes the diaphragm to vibrate. With the continuous revolutions of the plate, the parallel moving needle and connected parts gravitate toward the plate's center in a spiral line, etching into the wax film. When the recording is finished, the needle is removed and acid flows into the etched trough from a bottle located just behind the crank. Once etched from the acid, the trough is removed and the acid returns to the bottle. The wax film is dissolved and the plate is then moved to a reproducer.

On the reproducer, the plate is again mounted on a vertical spindle and revolves. The diaphragm in this machine has a needle that follows the spiral grooves, initiating diaphragm vibrations. The diaphragm and reproducing needle are in close proximity to the small end of a conical horn. The needle exerts little pressure on the disc, allowing maximum sound production through the horn. To play the gramophone, the crank is wound clockwise and the brake is released by a lever. The needle is placed on the disc and the gramophone is in operation.

Edison's phonograph and Bell's graphophone, which both used cylinders, were already commercially viable when Berliner patented his gramophone, but the gramophone had a distinct advantage over the rival machines: The discs could be easily mass-produced from molds. Berliner also concocted a revolutionary and original marketing scheme. He employed popular musical artists of the day, Enrico Caruso and Dame Nellie Melba among them, to record for him. The "Red Seal" recordings proved to be legendary and financially successful. Berliner also capitalized on Nipper, who listened to "His Master's Voice," a visual trademark recognized throughout the world since 1900.

by the American Bell Telephone Company, and he was hired as a research assistant. First in New York, then in Boston, Berliner spent the next seven years devoted to the development of the telephone with Bell Telephone and as an entrepreneur. In 1881, Berliner became an American citizen, married Cora Adler, and resigned from Bell Telephone. The couple moved to a small house in Washington, D.C., where he established himself in the private sector. He continued to tinker with the telephone and transmitter, surrendering the rights to his patents to the Bell Company.

The invention of the gramophone in 1886 proved to be a major contribution to the music recording industry. Thomas Alva Edison had already invented the cylinder phonograph in 1877 but then directed his attention to incandescent lighting. Berliner's gramophone represented a newer, more practical way of recording and reproducing sound—discs. His house on Columbia Road also served as center of operations for his gramophone business.

Berliner patented the gramophone in 1887, at the same time Edison returned to his work on the cylinder phonograph. Alexander Graham Bell's Volta Laboratory had also introduced the graphophone, similar to Edison's cylinder phonograph. Berliner's disc sound system employed a needle that vibrated from side to side within grooves. His first disc recording was also produced that year. In 1890, *Scientific American* published a descriptive article, complete with illustrations of the new machine, that further promoted the commercial success of the Berliner Gramophone Company.

Berliner returned to Europe twice, in 1881 and 1888, to present lectures and publicize his gramophone. The Hanover Institute of Technology celebrated Berliner's lecture and invention at the Electrotechnical Society of Berlin, firmly establishing the virtues of the gramophone. In 1900, a painting by Francis Barraud of a dog listening to a gramophone became the symbol for the Berliner Gramophone Company. Nipper the dog eventually became the trademark of the Victor Talking Machine Company, founded by colleague Eldridge R. Johnson.

Berliner's love of music surfaced again later in life when he turned to composing. He had always deeply appreciated the opportunities afforded to him as an American citizen. He composed a patriotic song, "Columbia Anthem," written for the 1897 national council of the Daughters of the American Revolution. The song was so well received that it was programmed by the U.S. Marine Band, performed at the White House, and served as a daily anthem sung by schoolchildren in Washington, D.C., and New York.

Berliner continued his experiments with musical instruments and acoustics. He developed a violin with the strings attached directly to the body of the instrument as a way to allow more unrestricted vibrations of the strings. For twenty years, he studied concert hall acoustics and invented acoustic tiles, acoustic cement, and parquet carpet to enhance sound production. The tiles could be applied to wall surfaces and were used in many buildings, including the Stanley Theater in Jersey City and the Leicester Theatre in London.

Berliner's efforts to repay American society included health industry reforms. When Berliner's daughter Alice became gravely ill because of a gastrointestinal condition, he concluded that the 30 percent mortality rate of infants was due to the use of raw milk. As a result of his extensive crusade for scalding milk and pasteurization, the federal government established specific milk standards.

He also championed women's rights. Contrary to the beliefs of many male scientists of his era, Berliner held that women, given the proper opportunities, would excel in science as much as men. In honor of his mother, he established the Sarah Berliner Research Fellowship for physics, biology, and chemistry in 1908. From 1909 to 1926, awards were presented to women in those disciplines, extending to psychology, geology, and other fields.

Toward the end of his life, Berliner was preoccupied with his fascination with flight. As early as 1906, he pondered the possibilities of aircraft, constructing a helicopter prototype by 1907 and developing the first radial aircraft motor. By 1926, he had constructed three helicopters that had trial flights. He also continued experimenting with rotary motors, designing one version after another. In 1920, along with his son Henry, Berliner successfully launched a helicopter that lifted straight up and proceeded in a forward direction. In 1923, an advanced version hovered in the air for fifteen minutes. The era of the helicopter had arrived, and Emile Berliner and son Henry were celebrated as creators.

In a letter to Cora in 1928, Berliner noted his wishes for a simple, inexpensive funeral, with piano music performed by his daughter Alice. On August 3, 1929, Emile Berliner died from a heart attack. He was buried in Rock Creek Cemetery, Washington, D.C.

Impact

The life of Berliner exemplifies the best of the human spirit. He immigrated to America with hopes of pursuing his dreams. With great resolve and patience, he conducted scientific investigations and experiments, forging new paths in communications, entertainment, acoustics, and aeronautical engineering. Berliner invented the flat-disc gramophone, the helicopter, the carbon microphone, acoustical tiles, and acoustic flooring. In 1913, the Franklin Institute awarded Berliner the Elliott Cresson Medal in recognition of his pioneering achievements in telephony and acoustics. The National Air and Space Museum in Washington, D.C., houses two of Berliner's helicopters in tribute to his accomplishments in aerospace technology, a 1924 Berliner Helicopter No. 5 and a Berliner 1932 monocoupe that was featured in air shows.

Although proud to be an American citizen, Berliner revered his roots. Devoted to religion and philosophy, he authored many articles on Zionism in support of Israel and vigorously supported the Hebrew University of Jerusalem. His convictions that one should not squander the blessings of American citizenship motivated him to thank America by advocating health industry reform and promoting women's rights. Hundreds of thousands of children's lives were spared because of Berliner's effective crusade to better inform the public about the perils of substandard health practices.

—*Douglas D. Skinner*

Further Reading

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Brooks, Peter W. *Cierva Autogiros: The Development of Rotary-Wing Flight*. Washington, D.C.: Smithsonian Institution Press, 1988. An account of Spanish aeronautical engineer Juan de la Cierva, who invented the autogiro, predecessor of the helicopter.

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See also: Alexander Graham Bell; Thomas Alva Edison; Peter Carl Goldmark; Elisha Gray; David Edward Hughes; Eldridge R. Johnson; James Russell; Granville T. Woods.

TIM BERNERS-LEE

British computer scientist

Berners-Lee's development of the World Wide Web began in March of 1989, when he found a means of bringing together the idea of hypertext and the young Internet. This combination paved the way for the rapid snowballing of ideas, software, and technology that grew into the contemporary World Wide Web.

Born: June 8, 1955; London, England
Also known as: Timothy John Berners-Lee (full name)
Primary field: Computer science
Primary inventions: World Wide Web; HTML

EARLY LIFE

Timothy John Berners-Lee was born in London on June 8, 1955. His parents were both mathematicians and were both a part of the team that built the first computer produced for commercial sale, the Ferranti Manchester Mark I. Berners-Lee grew up playing with discarded five-hole punch tape for computers and building his own "computers" out of cardboard boxes. He was also constantly taught mathematics by his parents.

The training served him well, as he sailed through coursework at both Sheen Mount Primary School and Emmanuel School in Wandsworth. At Queens College, Oxford University, Berners-Lee studied physics, which he saw as a compromise between mathematics and engineering. While at Oxford, he was caught hacking into the university computer system using a computer he had cobbled together with a soldering iron, an old television, some TTL gates, and an M6800 processor. After that incident, he was banned from the university's computer system.

Berners-Lee received his physics degree in 1976 and took a job with Plessey Telecommunications, where he worked on distributed transaction systems and message relays. In 1978, Berners-Lee left Plessey for D. G. Nash, where he wrote typesetting software. He left Nash in 1980 to work at the European Organization for Nuclear Research, known as CERN, in Geneva, Switzerland, where he would lay the groundwork for a creation that would literally change the way most people see the world.

LIFE'S WORK

CERN hired Berners-Lee as a consultant/software engineer. While he was there, he decided he needed to write a database program for his personal use that would allow him to store and retrieve information through the use of hyperlinks. Hyperlinks are connections from one document, or any type of data, to another, which allow that data to be dynamically organized. An example of this is the familiar hyperlink on Web sites that, when clicked upon, takes the user to another Web page. Berners-Lee wanted his program to use hyperlinks to help him keep track of the vast array of researchers employed at CERN and their individual research projects.

Berners-Lee named this database program Enquire, for an 1856 how-to book on domestic life titled *Enquire Within upon Everything*—a title that he saw as a near-perfect analogy for the information portal he was envisioning. While Enquire was never made public, it served as the seed idea for what would become the World Wide Web.

Berners-Lee left CERN in 1981, taking a technical design position at John Poole's Image Computer Systems, where he worked with communications software and firmware. During this hiatus, he never stopped thinking about developing broader applications for hypertext. In 1984, he returned to CERN, but it would be another five years before he could begin weaving his Web.

CERN still presented Berners-Lee with the same logistical nightmare he faced that led to the creation of Enquire. By 1989, however, his vision had expanded to include a global information space where computers were linked together and researchers from anywhere in the world could "surf" from one data collection to another. He envisioned a system in which data could be shared in a matter of days or hours. This new system would be a true democracy in that it would work on all computer platforms, in nearly all languages, across all geographic borders, and without bureaucratic delays or dictatorial censorship. In 1989, Berners-Lee submitted a proposal to CERN for just such a system.

After nearly a year had passed, Berners-Lee was given the go-ahead, and his "global hypertext" project, based on the Enquire program, got underway in October of 1990. He named the program "WorldWideWeb"; the Web browser was distributed within CERN in December and posted on the Internet by the summer of 1991. Berners-Lee also posted Web server software and began a word-of-mouth campaign for the project by posting on newsgroups. The number of servers, Web sites, and users continued to grow at astonishing rates. Cyberspace, once an environment inhabited primarily by physicists and other researchers in the hard sciences, was suddenly becoming a popular destination for college students, government agencies, businesses, and, as better Web browsers and faster network speeds became available, the general public.

Specifications and protocols for hyperlinks and the other critical bits of hypertext markup language (HTML) were initially specified by Berners-Lee and then refined after discussions by user groups. In October of 1994, Berners-Lee established the World Wide Web Consortium (W3C) at the Laboratory for Computer Sciences at Massachusetts Institute of Technology. The role of W3C is to coordinate the development of the Web by maintaining the standard protocols for HTML.

As the cultural importance of the Web became evident, Berners-Lee became a celebrity. In 1997, he was awarded an Order of the British Empire for his work establishing the Web. He won a MacArthur Fellowship "genius grant" in 1998. In 1999, *Time* magazine named Berners-Lee one of the 100 Greatest Minds of the Century, and he was named the inaugural holder of the 3Com Founders Chair at MIT, where he was allowed to continue his Web work as a senior research scientist. In July, 2004, he was knighted by Queen Elizabeth II and became chair of the Computer Science Department at the University of Southampton. In June, 2007, Berners-Lee joined the elite Order of Merit, a gift bestowed by the Queen.

Impact

The World Wide Web has changed the world in a number of ways; namely, it has democratized information. The Web makes uncensored news reports, blogs, and alternative or marginalized points of view readily available to most of the world. Individuals who may have never had access to the corporate or governmental news media have found such access available on the Web. The very nature of the medium is such that a hypertext document produced by a poor villager in Laos can theoretically reach as many readers as a document produced by such established newspapers as *The New York Times*.

The Web has also changed the way information currency and relevancy is viewed. Thanks to the instantaneous nature of the Web, live Web cams and blogs can bring users to both sides of the front lines of war zones in real time. Such instantaneous and global access to data makes it difficult for information to be suppressed. The Web user's ability to tailor the flow of information to fit only his or her interests means that the relevance of a particular story is no longer determined by an editor

Fourth International
World Wide Web Conference
"The Web Revolution"

Tim Berners-Lee, inventor of the World Wide Web. (AP/Wide World Photos)

UDIs, HYPERTEXT, WWW, HTML, AND A LINKED WORLD

Tim Berners-Lee's dream was to create a common information space in which people engage in communication through the sharing of information via hypertext links. Hypertext is, simply put, a text command on one computer that will lead a user to a related piece of information that resides in another computer. That notion of linking is the very basis of the Web.

Berners-Lee made this possible by creating a number of smaller components that were necessary to make the hypertext linking appear seamless to the user. The first component was to create a means of giving each piece of data available on the Web its own unique identity so that hyperlinks could be built to link to a specific piece of data. He did this by creating a protocol called the universal document identifier (UDI; now called the uniform resource locator, or URL), perhaps best known as a "Web address." Berners-Lee also needed a language with which to write hypertext code and, later, page layout and formatting specifications. This Web-specific language was known as hypertext markup language (HTML). Next, Berners-Lee needed to construct a protocol governing the retrieval and presentation of data over the Web, which he named hypertext transfer protocol (HTTP).

Next, Berners-Lee constructed the first hypertext editor so that documents could be prepared for presentation on his fledgling Web. In 1990, he completed the editor, which he named "WorldWideWeb." There was also the question of how those hypertext documents would be made available, so Berners-Lee also wrote the first Web server software, called "httpd," for "hypertext transfer protocol daemon."

The first Web site went online at the European Organization for Nuclear Research (CERN) on August 6, 1991. The initial site had pages explaining the Web and how to obtain a browser and set up a server. With all the groundwork in place, Berners-Lee began circulating the software, first among the physicists at CERN, then by posting the software on the Internet and talking about it via posts in newsgroups.

As new Web browsers were developed and made available—Erwise, Viola, Cello, and Lynx being among the first—the number of users grew. When a student at the University of Illinois, Marc Andreessen, developed the user-friendly Mosaic (released in 1993), the first browser to incorporate inline graphics, Web usage skyrocketed. Andreessen went on to develop the Netscape Navigator Web browser, released in 1994.

From an idea designed to create an information utopia, the World Wide Web has become, in a short period, a commercial backbone, a critical component of the U.S. government and military, a tool for continual education, information gathering, and entertainment, and one enormous social network. The future Web promises even more, with bigger bandwidth, more content, and metadata that will allow searching and indexing to become even more precise.

serving a broad community but rather by the needs and desires of the end user. These changes have altered the way news and information is covered and packaged for the end user, resulting in a wider variety of information for the user.

With the advent of the Web, new businesses cropped up and continued to do so as entrepreneurs explored the possibilities of the new medium. The Web changed the way businesses were run, as most corporate outlets and even small-town stores established their own Web presence. Sites like Amazon.com proved that using the Web to change the extant business model for bookstores was a multimillion-dollar idea. As a result of peer-to-peer file sharing cutting deeply into music industry profits, the industry became more Web-driven.

The Web also holds the promise of creating a society in which more people have the freedom to work or be educated from home rather than having to travel to a job or campus. Perhaps the most important impact of the World Wide Web is that it is allowing "netizens" to share information, research, news, entertainment, old books, photos, music, and conversation in a way that can unite people worldwide. This remains a critical part of Berners-Lee's dream for the Web.

—B. Keith Murphy

FURTHER READING

Berners-Lee, Tim. *Weaving the Web: The Original Design and Ultimate Destiny of the World Wide Web*. New York: HarperCollins, 2000. Although lacking in technical depth, the book explains how and why the World Wide Web came into being. Berners-Lee shares the glory of creating the WWW revolution and holds that the Web can be a means of creating more harmony within world society.

_______, et al., eds. *Spinning the Semantic Web: Bringing the World Wide Web to Its Full Potential*. Cambridge, Mass.: MIT Press, 2005. A rather technical look at the future of the World Wide Web, the book focuses on the tagging of data for more reliable and faster indexing. This work is of most interest for Berners-Lee's foreword.

Hafner, Katie, and Matthew Lyon. *Where Wizards Stay Up Late: The Origins of the Internet*. New York: Simon & Schuster, 1996. Tells the tale of the birth of the modern Internet. Ranging from the launch of Sputnik and the Defense Department's Defense Advanced Research Projects Agency (DARPA) network projects to the Web, Hafner's book puts Berners-Lee's contribution into its context within this fascinating and arcane history.

See also: Marc Andreessen; Robert Cailliau; Vinton Gray Cerf; Philip Emeagwali; Bill Gates; Bob Kahn; Robert Metcalfe; Larry Page.

CLIFFORD BERRY

American electrical engineer

While John Vincent Atanasoff developed the concept for the Atanasoff-Berry Computer (ABC), Berry deserves equal credit for the detailed design and construction. Berry's work on the ABC showed that an electronic computer could be built for digital calculation. This influenced future development of the computer.

Born: April 19, 1918; Gladbrook, Iowa
Died: October 30, 1963; Plainview, New York
Also known as: Clifford Edward Berry (full name)
Primary field: Computer science
Primary invention: Atanasoff-Berry Computer

EARLY LIFE

Clifford Edward Berry was born in Gladbrook, Iowa, in 1918. He was the first of four children born to Fred and Grace Strohm Berry. Fred, a self-taught engineer, had an electrical appliance and repair store in Gladbrook and worked on electrical projects, including building the small town's first radio. Clifford, also known as Cliff, showed early interest in engineering and electronics when he, with his father's oversight, built his own radio.

The Berry family moved to Marengo, Iowa, when Cliff was eleven. Tragedy struck the family when Fred, a manager at the Iowa Power Company, was shot and killed by an employee who had been fired from his job. Before his death, Fred had decided that Cliff would attend Iowa State College (now Iowa State University) because its college of engineering had a national reputation. When Cliff was ready for college, the family moved to Ames, Iowa, and he studied electrical engineering at Iowa State. There he excelled, graduating in 1939. One of Berry's professors recommended him to John Vincent Atanasoff when the latter was looking for an electrical engineering graduate student to assist in his computer project.

LIFE'S WORK

In the spring of 1939, Berry began to work on Atanasoff's project to build a prototype of an electronic digital computer. For Atanasoff's research, he had to find solutions to large and complex sets of equations. Doing this by hand was extremely tedious. It could take a human 125 hours to solve twenty equations and twenty unknowns. Atanasoff designed a fully electronic computer that could solve a system of thirty equations and thirty unknowns.

Berry's skill in electronics complemented Atanasoff's skills in math and physics. Berry took Atanasoff's rough sketches of some parts of the machine and worked out the details. Eventually, Berry worked independently on the machine without detailed instructions from Atanasoff and suggested his own improvements. They worked in the basement of the physics building next to a student workshop, where they could carefully build each component and test it before moving on.

Berry found that vacuum tubes were expensive, used a lot of space, emitted much heat, and broke often. After testing, he chose a kind that consumed the least power and worked well with the condensers. The tubes provided enough voltage to recharge the condensers, and the condensers provided enough voltage to actuate the tubes.

By the end of 1939, Berry and Atanasoff had a working prototype, which they demonstrated to Iowa State officials. The prototype was a breadboard-size device with the electrical components mounted crudely on its surface. While small, the machine had all the important parts to show that they could make the design work. They received a grant to build a full-scale machine, and the college decided to apply for a patent.

Atanasoff, with Berry's assistance, wrote a thirty-five-page manuscript entitled "Computing Machines for the Solution of Large Systems of Linear Algebraic Equations," with drawings of the machine. The manuscript was sent to a college-appointed lawyer to proceed with the patent application. While Iowa State College officials refused to grant a portion of income from a patent to a graduate student, they agreed not to interfere if Atanasoff chose to give Berry a portion of his 50 percent. Atanasoff wanted to acknowledge the importance of Berry's contribution. In the end, however, the attorney and the college never applied for the patent.

Berry received his master of science in physics in 1941. On May 30, 1942, he married Martha Jean Reed, Atanasoff's secretary. They had two children, Carol and David. Also that year, Atanasoff and Berry produced a working electronic special-purpose computer, known as the Atanasoff-Berry Computer (ABC). This computer employed various new techniques, including novel uses of logic circuitry and regenerative memory. However, the part of the machine designed to record intermediate results on paper worked for small systems of equations, not for large ones.

The U.S. entry into World War II ended Berry and Atanasoff's work and may have prevented their innovations from being published, patented, and given proper credit. They both left Iowa for jobs in the defense industry. Atanasoff went to work for the Naval Ordnance Laboratory in Maryland. Berry moved to Pasadena, California, where he took a position with Consolidated Engineering Corporation (CEC) for defense-related work. The Atanasoff-Berry Computer remained in the basement of the physics building, where Atanasoff and Berry had built it. When neither returned to Iowa after the war, the chair of the Physics Department needed the space in the basement and disassembled the ABC in 1948.

While employed at CEC, Berry arranged with Iowa State to complete the requirements for a Ph.D. in physics, which he received in 1948 with his dissertation "The Effects of Initial Energies on Mass Spectra." CEC's market strength was in mass spectrometers, which produced large amounts of data. To analyze the data, one had to solve a set of simultaneous linear equations similar to the work Atanasoff had done. Berry (with Sibyl Rock) developed and patented an analog computer to accomplish this in 1945.

In 1949, Berry became chief physicist at CEC, and he was promoted to assistant director of research in 1952. In 1959, he became director of engineering of the Analytical and Control Division and also served as technical director. Berry received nineteen patents in the area of mass spectrometry and eleven in the areas of electronics and vacuum tubes.

THE ATANASOFF-BERRY COMPUTER (ABC)

The ABC was the size of a large desk or chest freezer and weighed about seven hundred pounds. All the parts were mounted on a metal frame. There was an operator's control console on top with numerous switches, buttons, meters, and lights. Underneath the console was the arithmetic unit (to perform addition and subtraction), which contained over two hundred vacuum tubes. Beside it was the equipment for input and output. Two rotating drums served as the memory. Each drum had sixteen hundred capacitors set into its skin in thirty-two rows. The capacitors represented a digit by being charged positively (1) or negatively (0). Each drum stored thirty fifty-bit numbers (fifteen-place decimal numbers). Since the capacitors drained their charge about the time a drum made one complete revolution, Clifford Berry and John Vincent Atanasoff designed a circuit to regenerate the charge on each rotation. While crude, this became the basis of the modern dynamic random access memory (RAM) in computers.

Because the machine's memory could not hold enough of the intermediate results required in the calculation, these results needed to be stored and reloaded later. Berry and Atanasoff used high-voltage arcs to burn holes in paper. A hole signified a 1 and no hole a 0. In the binary, or base-2, system that they used, there are only 1's and 0's (unlike the decimal system that has the numerals 0 through 9). After the intermediate results were burned in, the paper was read when it was passed between electrodes at a lower voltage than was used to create the holes. The arc would form in the reader if there was a hole in the card, but not if the paper remained intact.

Berry's master's thesis, "Design of Electrical Data Recording and Reading Mechanism," presented the best means for recording and reading of intermediate results. He found the correct voltage to write (3,000 volts) and to read (2,000 volts), which allowed the ABC to record the entire contents of one memory drum in one second; the correct thickness of paper; and the correct spacing of electrodes to write and read.

For small systems of equations, the ABC was much faster and more reliable than hand calculation. ABC's calculating speed far outstripped its ability to handle input and output. The calculations had errors only once every 100,000 times, so the machine was successful for these small systems of equations. However, while this small error made no difference for small systems of equations, large systems required hundreds of thousands of operations. Thus, the error would occur and produce incorrect results.

In 1963, Berry left CEC for a position at the Vacuum-Electronics Corporation in Plainview, New York. Before his family could join him, he died suddenly on October 30. His death was listed as a "possible suicide" from suffocation.

IMPACT

Berry played a key role in the development of the electronic computer. Berry and Atanasoff's work communicated the ideas of fully electronic digital logic and dynamic regenerative capacitor storage to other early computer designers and played an important role in the eventual development of a fully programmable electronic general-purpose computer.

Particular components of the ABC were innovative and became basic elements in computers. The machine pioneered a regenerative memory. It used regenerative pulses to stop the charges in the capacitors from "leaking" away. This technique is still the basis of modern dynamic random access memory (RAM). Other innovations included the use of vacuum tubes, the use of binary numbers, and the use of electronic logic.

In the 1960's, when the legal battles over who invented the first electronic computer began, Atanasoff began to refer to the machine as the "Atanasoff-Berry Computer," or "ABC," to give Berry appropriate credit. Atanasoff said that the assembly procedure for the logic circuit that Berry had designed had made the circuits perfect. The ABC would not have been built and would not have worked without Berry's contribution.

—*Linda Eikmeier Endersby*

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Gustafson, John. "Reconstruction of the Atanasoff-Berry Computer." In *The First Computers—History and Architectures*, edited by Raúl Rojas and Ulf Hashagen. Cambridge, Mass.: MIT Press, 2000. Technically detailed chapter detailing the reconstruction of the Atanasoff-Berry Computer in 1997. Provides some information about the working of the computer that cannot be found elsewhere. Illustrations, sources, index.

Hally, Mike. *Electronic Brains: Stories from the Dawn of the Computer Age*. Washington, D.C.: J. Henry Press, 2005. Readable book with details of various machines and personalities significant in the development of the modern computer. Includes one chapter with information on Berry and Atanasoff's work. Includes useful appendixes explaining technical terms, binary mathematics, and parts of the modern computer. Illustrations, references, index.

Mollenhoff, Clark R. *Atanasoff: Forgotten Father of the Computer*. Ames: Iowa State University Press, 1988. Very readable work that provides many details on Berry's life and work in the first half of the book. Second half of book has little on Berry. Illustrations, references, index.

See also: John Vincent Atanasoff; John Presper Eckert; John William Mauchly; Konrad Zuse.

SIR HENRY BESSEMER

British engineer

Bessemer developed a relatively inexpensive process for the mass production of steel, which was previously a scarce and expensive commodity. His Bessemer converter helped launch a revolution in manufacturing commonly termed the Second Industrial Revolution.

Born: January 19, 1813; Charlton, Hertfordshire, England
Died: March 15, 1898; London, England
Primary field: Manufacturing
Primary invention: Bessemer process

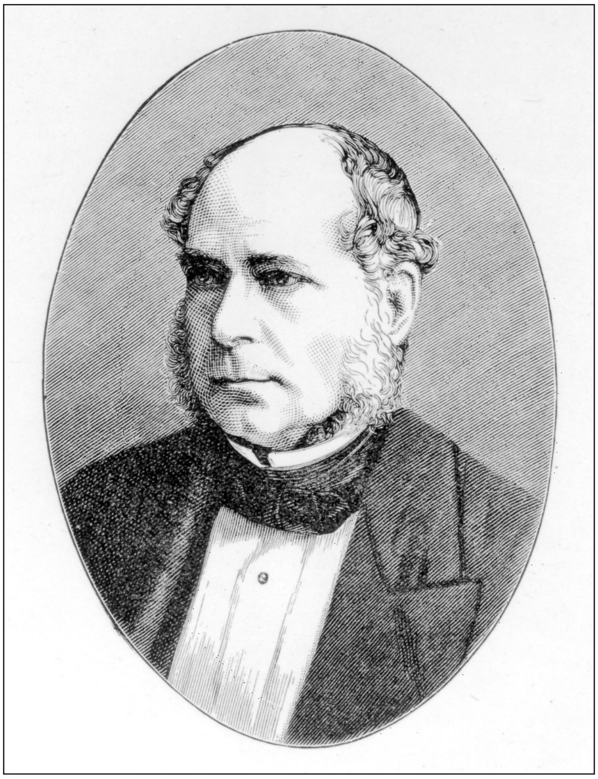
EARLY LIFE

A grade school dropout, Henry Bessemer nevertheless went on to become one of England's most prolific inventors, registering 110 patents and becoming fantastically wealthy in the process. His informal education stemmed almost exclusively from his father's influence. Anthony Bessemer was a successful typefounder and inventor who made his fortune developing a process and dyes for making gold chains. Bessemer learned metallurgy in his father's type foundry, built in the grounds of the family house at Charlton. When only seventeen years old, he founded his own business for producing art metals and fusible alloys. By age twenty, he was an exhibitor at the Royal Academy and had invented a process for making dated embossed stamps used on title deeds and other government documents. Formerly, stamps were taken off old deeds to save the buyer the £5 government fee. With the new embossed stamp dyes, which were capable of producing thousands of dated facsimile impressions, the British government made a handsome profit in fees. Married at twenty-one, Bessemer had a home built at Northampton Square. As his wealth grew, he had larger London-based homes built at St. Pancras, Highgate, and Denmark Hill. He built a foundry at his residence (called Baxter House) in the London suburb of St. Pancras.

Bessemer earned considerable money developing a process for compressing powdered graphite dust to form lead pencils and for embossing velvet wallpaper by using a succession of steamrollers. He also developed a steam-driven fan for ventilating mines, an improved method for producing sheet glass, and a compact-sized press using a screw extruder for efficiently extracting over 600 gallons of juice per hour from sugarcane, for which he received the Royal Society of Arts Albert Medal. However, his main fortune was made in 1843, when he developed a complex yet cheap process for turning bronze into a dust, oxidizing the dust to produce a brilliant gold color, and using it to make gold paint. The process involved a series of six steam-powered machines. It took thirty-five years for others to duplicate the process. Meanwhile, Bessemer became wealthy producing the stylish color used extensively in the time period termed the Gilded Age. While a brilliant inventor, Bessemer was also an astute businessman. For this combination of abilities he became known as "the ingenious Mr. Bessemer."

Life's Work

In 1853, as Bessemer turned forty, the Crimean War began. Anglo-French forces stood against Russia, which had by far the largest army in Europe. At the start of the war, Bessemer produced experimental conical shells that were far heavier than cannon balls and with spiral grooves cut into the sides. Escaping gases would make the shell spin and deliver its payload with considerable accuracy. In November, 1854, he patented the artillery shell but found no interest in it by the British War Department. The French emperor Napoleon III seemed intrigued, but wrought iron cannon barrels proved too weak to handle the heavy gas pressure emitted by the shell. Attempts to line the barrel with steel, a rare commodity at the time, proved insufficient. Bessemer left France obsessed with thoughts about how to produce stronger cast iron. Within a year, he found the answer—blowing air through the bottom of a vat of molten iron. His first experiment sent in too much air at once, producing a volcanic-type reaction that nearly destroyed his Baxter House foundry in St. Pancras.


Sir Henry Bessemer. (Library of Congress)

In 1855, Bessemer successfully produced a low-grade steel from molten pig iron in a side-blown fixed converter without any external source of heat. The Bessemer converter was an egg-shaped vat that held molten iron. Cold air was blown into tiny perforations in the bottom, removing carbon and other impurities in the iron. The blast of air also superheated the iron, allowing it to be easily poured. Workers needed no special skills. The end result was high-quality steel produced cheaply. He patented the process, and on August 24, 1856, he described the process in a paper "The Manufacture of Iron Without Fuel," presented at a meeting of the British Association in Cheltenham. The presentation was important enough to be published in its entirety in the London *Times*. Immediately, five firms eager to save money in time, labor, and fuel applied to produce under Bessemer's patents.

The wrought iron producers who tried the Bessemer process failed to produce quality steel. The cause was soon found. British pig iron was phosphorus-rich, which led to brittleness in forging. No immediate solution to the problem could be found. In his own experiments, Bessemer was fortunate to use iron from the one place in England that did not contain phosphorus.

Bessemer proceeded to establish steelworks in Sheffield in 1858, using phosphorus-free ore mainly imported from Sweden. It was in Sheffield where the bottom-blown tilting converter was introduced in 1860. Soon, the Sheffield plant could undersell all competitors since crucible steel cost twice as much as Bessemer steel. In the United States, the Bessemer process was patented in 1857, but Bessemer's priority was challenged by William Kelly. As the prospect of a long legal battle threatened, a settlement was reached in which the two rival companies consolidated. In 1865, the first U.S. plant using the Bessemer process began operation in Troy, New York, to be soon followed by one in Harrisburg, Pennsylvania. In the United States, thirteen cities would be named Bessemer.

In spite of its initial drawbacks, the process made Bessemer a multimillionaire. His methods were ten times faster than any previous methods, used no fuel once the pig iron melted, and could make thirty tons of steel at once rather than the fifty pounds using other methods. By 1879, Sydney Gilchrist showed that phosphorus could be removed by using basic instead of acidic furnace linings and fluxes. The open-hearth steelmaking process was developed, which became established in England. However, the rest of Europe and the United States continued to use the standard Bessemer process. One American who made a fortune from it was Andrew Carnegie. It was not until 1907 that the open-hearth method surpassed the Bessemer method in the production of steel.

Old age did not slow up Henry Bessemer. He invented a solar furnace and designed and built an astronomical telescope, as well as machines to efficiently polish diamonds. His last ventures were in the construction of steamships designed to ease seasickness on the rocky trip across the English Channel. He invented a system to keep the cabin stable by mounting it on gimbals. Thus, the cabin would remain horizontal as the ship pitched in the waves. A prototype was built by Maudslay, Sons and Field in 1875. It had two sets of paddle wheels and was extremely difficult to steer. It twice crashed into the pier at Calais and was abandoned after its maiden voyage.

In 1879, Bessemer was knighted and made a fellow of the Royal Society. His final years were spent designing numerous improvements to his own home and those of his children. He died at his Denmark Hill estate in 1898.

THE BESSEMER PROCESS

The Bessemer process was used to manufacture steel from molten pig iron. The principle involved is that of oxidation of the impurities in the iron by the oxygen of air that is blown through the molten iron. The heat of oxidation raises the temperature of the mass, keeping it molten during operation. The process is carried on in a large, egg-shaped container called the Bessemer converter, which is made of steel and has a lining of silica and clay or of dolomite. The capacity ranges from eight to thirty tons of molten iron; the usual charge is fifteen or eighteen tons. At its narrow, upper end, it has an opening through which the iron to be treated is introduced and the finished product is poured out. The wide, bottom end has a number of perforations through which the air is forced upward into the converter during operation. The container is set on pivots so that it can be tilted to receive the charge, turned upright during the "blow," and inclined for pouring the molten steel after the operation is complete. As the air passes upward through the molten pig iron, impurities such as silicon, manganese, and carbon unite with the oxygen in the air to form oxides; the carbon monoxide burns off while the other impurities form slag. Dolomite is used as the converter lining when the phosphorus content is high; the process is then called basic Bessemer. The silica and clay lining is used in the acid Bessemer, in which phosphorus is not removed. In order to provide the elements necessary to give the steel the desired properties, another substance (often spiegeleisen, an iron-carbon-manganese alloy) is usually added to the molten metal after the oxidation is completed. The converter is then emptied into ladles, from which the steel is poured into molds; the slag is left behind. The whole process is completed in fifteen to twenty minutes. The Kelham Island Museum at Sheffield maintains an early example of a Bessemer converter.

IMPACT

Prior to the Bessemer process, steel was expensive and difficult to produce. It was used largely for specialized cutting tools and fine swords. Henry Bessemer pioneered the steel industry. He made steel plentiful and relatively cheap to produce. Lighter, stronger, and more flexible than either cast iron or wrought iron, steel became a driving force behind the Second Industrial Revolution. It would be used for skyscrapers, bridges, weapons, machines, tools, and transportation. Steel became the basic component of the physical structure in modern urban industrial society. Although Bessemer's process would be supplanted by other steel-producing processes in the twentieth century, especially the oxygenization process of the 1950's, it nevertheless began the rapidly accelerating process of worldwide steel usage on a large scale.

As an individual, Bessemer stands out as not only an innovative genius and capable businessman but also one of the most important inventors of the nineteenth century.

—*Irwin Halfond*

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See also: Abraham Darby; Robert Stirling.

EDWIN BINNEY

American chemist

Binney's first major invention was dustless chalk, and he developed several manufacturing processes for black carbon, but he is best remembered for his 1903 invention, along with his cousin C. Harold Smith, of Crayola brand crayons, which were marketed as a children's toy.

Born: 1866; Shrub Oak, New York
Died: December 18, 1934; Greenwich, Connecticut
Primary field: Chemistry
Primary inventions: Crayola crayons; dustless chalk

EARLY LIFE

Edwin Binney's father, Joseph W. Binney, came to upstate New York from England in 1860. He started the Peekskill Chemical Works in Peekskill, New York, in 1864, two years before Edwin's birth. The chemical company initially produced a hardwood charcoal and a black pigment called lampblack. The company moved to New York City in 1880, and Edwin joined the company, as did his cousin C. Harold Smith. Smith was born in London in 1860. Upon reaching adulthood, Smith immigrated to New Zealand, where he fell in love with a Maori woman and narrowly escaped death at the hands of her tribe. He decided the United States would be safer and moved to New York to join his extended family.

Joseph Binney retired from the business in 1885, and the two cousins changed the name of the company to Binney & Smith—a partnership that was eventually incorporated in 1902. The product line was expanded to include black shoe polish, ink, and chalk. Red paint, used to paint barns, was another early product. With the discovery of oil in Pennsylvania came a new type of petroleum-based black pigment, and the cousins took an active role in production and development of carbon black from natural gas wells. They even bought into some of the companies that produced the carbon black. This new pigment soon became the main ingredient in many of the company's products. One of the products affected by the black pigment was the tire manufactured by B. F. Goodrich. Goodrich produced white rubber tires. (The color was caused by zinc oxide in the rubber compound.) When Goodrich used Binney & Smith pigment to expand its product line to include black tires, the company discovered that the black pigment not only changed the color of the product but also made it five times more durable. Soon after, white tires disappeared from America's roadways. The growth of the tire business led Binney & Smith to other inventions, including a formula for putting black carbon into pellets to eliminate dust from the production process.

Binney and Smith made great partners. Binney was product- and finance-oriented, while Smith was a master salesman. Soon Smith had expanded the company's customer base for black pigment worldwide, and the company prospered. The company's headquarters were moved to Easton, Pennsylvania, in 1902 when the company incorporated. In 1900, the company had bought an old water-powered mill on Bushkill Creek near Easton and used it to grind up old slate from the region's many slate quarries. The resulting product was a pencil of superior quality. This product led Binney & Smith into the education market—a market that was to make them famous. Meetings with school teachers convinced Binney of the need for a better quality of chalk and lower-priced crayons. This led to the invention of An-Du-Septic, a dustless chalk that was sturdier than traditional chalk. In 1904, Binney's invention won a gold medal at the St. Louis World's Fair.

LIFE'S WORK

At about the same time that experiments were being conducted on dustless chalk, there was similar work being done on crayons. The first invention was a black wax crayon called Staonal ("stay on all"), named so because it would work on any type of surface; Staonal was designed as a marker for writing on boxes and barrels. The overnight success of Staonal led to experiments with other types of pigments to create colored wax crayons for use by schoolchildren. Artists already had access to imported crayons, but the cost of these tools was prohibitive for other than professional use. From the beginning, the concept was to use nontoxic pigments, since the end consumer was to be small children. Binney's wife, Alice, was a former schoolteacher, and she took a special interest in the product. In fact, she is credited with creating the name "Crayola." Teachers were already familiar with the company's quality pencils and chalk, so the introduction of Crayola crayons was an overnight success.

By 1911, the company had become quite profitable and allowed Binney and his family to spend much time in St. Lucie County, Florida, where he owned over one thousand acres of citrus groves. The community was known then as Fort Pierce Farms. Binney was an avid sportsman and fisherman. He was also a community activist and contributed much to his adopted Florida home. In 1919, Binney advocated having Fort Pierce become a

Crayola
8 NEW
KIDS' CHOICE COLORS
BY KIDS · ABOUT KIDS
64
CRAYONS
1958-2008
50th Birthday of the 64 Crayon Box!
BUILT-IN PERFECT-TIP SHARPENER
Nontoxic

In 2008, Crayola celebrated the fiftieth anniversary of its sixty-four-count box with a limited-edition set that included eight new colors chosen by children. (AP/Wide World Photos)

CRAYOLA CRAYONS

The first boxes of eight Crayola crayons were produced by Edwin Binney, along with his cousin C. Harold Smith, in 1903. The factory was in Easton, Pennsylvania. The price for a box of eight crayons was five cents. Binney's London-born wife, Alice Stead Binney, created the name "Crayola" from the French word *craie* (chalk) and "ola" (oleaginous, oily), since the crayons were produced from a petroleum-based wax. The eight original colors were black, brown, blue, red, purple, orange, yellow, and green. Today, there are more than 120 colors produced by Crayola, including some that sparkle, glow in the dark, and wash off of walls. Actually, Binney did not invent the crayon, he merely invented an improved crayon. Crayons had been invented earlier in Europe and were basically a mixture of charcoal and oil. Binney's contribution was to produce a better quality crayon that was nontoxic and affordable and to market it as a toy for children.

By 1920, Crayola products had expanded to include special crayons for art students and fine art crayons that could be sharpened. In 1948, the company began providing in-school training for art teachers across the nation. In 1958, the first box of sixty-four crayons was marketed. The box even had a built-in sharpener. In 1978, the company's product line expanded to include Crayola markers, and in 1987 washable markers were introduced. In 1990, eight crayon colors were retired into the Crayola Hall of Fame; these were maize, raw umber, lemon yellow, blue gray, orange yellow, orange red, green blue, and violet blue. However, a year later, those retired colors were offered in a special collectors' edition. The company's ninetieth birthday celebration in 1993 included the introduction of the company's largest crayon box ever, ninety-six colors. The 100 billionth Crayola crayon was produced in 1996, and this number continues to increase by more than 13.5 million every day. The company's best seller is the box of twenty-four crayons—a quantity that provides adequate variety, but at a reasonable price.

Binney & Smith changed its name to Crayola in 2007. The Crayola brand name has 99 percent name recognition among American consumers. The scent of crayons, according to studies, is one of the most recognizable scents to the American people. Crayolas are sold in over eighty countries and are packaged in boxes written in twelve languages. The invention of Edwin Binney has transformed the way the world looks at art and has made it economically possible for every child to be a budding artist. Many of the world's great artists of the past century likely started their career with a box of wax crayons from Binney & Smith. For example, American Gothic artist Grant Wood began his career with a Crayola contest. Wood later stated that by winning the Crayola contest, he was given the confidence and encouragement to pursue a career in the art world.

port city with an inlet to the Atlantic Ocean that would accommodate oceangoing vessels. Through his support, this was accomplished in 1922. In 1928, he contributed the funds to restore a bridge that linked the city with the nearby beach. When the Great Depression began in 1929, Binney put up his own money to keep the doors open at the St. Lucie County Bank. He also helped establish the local troop of Sea Scouts (a division of the Boy Scouts of America) and donated land that eventually became the Fort Pierce Coast Guard Station and the Pelican Yacht Club. Binney had four children: Edwin, Jr., Dorothy, Helen, and Mary. Although his son died at a young age, his namesake grandson, Edwin III, became a noted philanthropist in his own right.

Although Binney seemed happy in his life and career, such may not have been the case for his partner, Smith. In 1929, because he despised his fortune, Smith sponsored a contest, with a $1,000 prize, for the best idea as to how he could use his $10 million fortune for the good of humanity. The winning idea, submitted by a Columbia University psychology professor, was the creation of a C. Harold Smith Institute of Mental Hygiene. The institute never materialized. Smith died in 1931—three years before Binney. Both Binney and Smith were inducted into the Toy Industry Hall of Fame in 2006.

The Smithsonian National Museum of American History Archives Center houses the Binney & Smith archival materials dealing with technology, inventions, and innovations. These archives include advertising materials, financial and sales records, and various research and development records. The company itself has been a subsidiary of privately owned Hallmark Cards, Inc., since 1984. In 2007, the company had over 2,600 employees.

IMPACT

The Crayola brand name of Binney & Smith has become one of the most recognizable and most respected brands in the world. The green-and-yellow box equates to fun in the minds of children everywhere. The company has always been known for colors—from red barns to black automobile tires—but the more than 120 different crayon colors has been the lasting legacy of Binney. One study claimed that the average child uses 730 crayons by his or her tenth birthday—thus making crayons one of the most often used products in the world. All of this has been accomplished with very little advertising; the product has sold itself. To this day, Crayola company executives will still sign official correspondence with a crayon. After all, crayons are the company's franchise.

—*Dale L. Flesher*

FURTHER READING

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Kitchel, Helen Binney. *Memories*. Greenwich, Conn.: n.p., 1978. This memoir by Binney's daughter tells of her years growing up in Connecticut, which was near the New York office of her father's company. Although the book does not deal with inventions, it gives background on Binney's life.

_______. *More Memories*. Greenwich, Conn.: n.p., 1979. This memoir by Binney's daughter expands her life story, including some travels with her father.

Mehegan, Sean. "Brand Builders: The Color of Money." *Brandweek*, September 15, 1997, 22. Discusses the Crayola advertising, or the lack thereof, over the years. Much of the article deals with new videos and video games that the company was planning to introduce.

Petroski, Henry. *The Pencil: A History of Design and Circumstance*. New York: Alfred A. Knopf, 1993. Although mostly about the history of pencils, this volume includes a section on the history of crayons. Includes bibliographical references and index.

See also: Joshua Lionel Cowen; Beulah Louise Henry.

GERD BINNIG

German physicist

Binnig made significant contributions to the field of physics with his invention of the scanning tunneling microscope and the atomic force microscope. These two microscopes were key to the emergence of nanotechnology and opened new fields of scientific research.

Born: July 20, 1947; Frankfurt am Main, West Germany (now in Germany)
Also known as: Gerd Karl Binnig (full name)
Primary field: Physics
Primary inventions: Scanning tunneling microscope; atomic force microscope

EARLY LIFE

Gerd Karl Binnig (gehrt kahrl BIH-nihk) was born in Frankfurt am Main, West Germany, on July 20, 1947. His mother, Ruth Bracke Binnig, was a drafter and his father, Karl Franz Binnig, worked as a machine engineer. Binnig and his younger brother spent their childhood playing among the ruins left by World War II, an experience that had a significant influence on his life. He attended both elementary and secondary school in Frankfurt and Offenbach, as his family lived in both cities at various times during this period. Although he did not really understand what a career in physics entailed, by the age of ten Binnig had decided that he wanted to be a physicist.

Once he started studying physics, Binnig began to question his choice. It was theoretical physics in particular that caused him to doubt whether he had chosen the right career. He found the discipline lacking any philosophical or imaginative elements. For a while, he became very interested in music and devoted more time to playing and writing music than to studying physics. Having grown up in a family that appreciated classical music, he learned to play the violin at fifteen and played in the school orchestra. Then, because of his brother's influence, he developed an appreciation for music by groups such as the Beatles and the Rolling Stones. Eventually, he was playing in rock bands and writing songs himself.

Physics was, however, still a part of Binnig's life and gained new importance when he began studying at Johann Wolfgang Goethe University in Frankfurt. He was placed in a program directed by Dr. W. Martiessen and worked under the supervision of Dr. E. Hoenig. During his study with these professors, Binnig had the opportunity to perform experiments. This emphasis on doing rather than reading about the discipline restored his interest in physics. He received his bachelor's degree in 1973 and a doctorate in physics in 1978. His dissertation dealt with superconductivity, the phenomenon of zero-resistance conduction at extremely low temperatures (near absolute zero) in metals and ceramics.

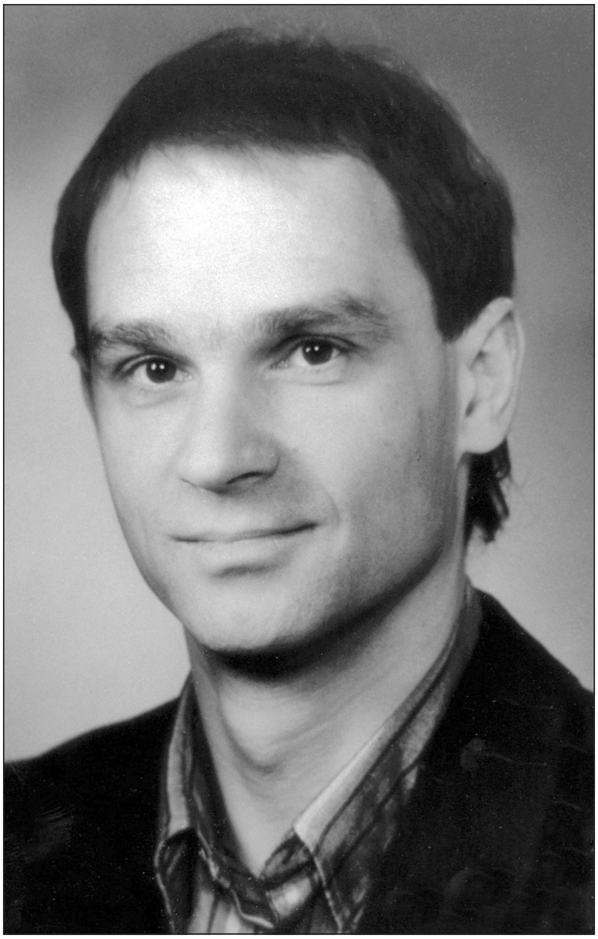
While attending the university, he met Lore Wagler, a psychology student. In 1969, they married, and she was instrumental in convincing him to take a position at the International Business Machines (IBM) Research Laboratory in Rüschlikon, Switzerland, immediately upon completing his Ph.D. The couple had two children, a daughter and a son.

LIFE'S WORK

Accepting the position at the IBM lab provided an excellent career choice for Binnig. There he joined a research team that included Christoph Gerber, Edmund Weibel, and Heinrich Rohrer. Both Rohrer and Binnig had been doing research in the field of superconductivity. Rohrer did much to renew Binnig's enthusiasm for physics by his attitude toward scientific investigation, which combined humor with serious devotion to research. In 1981, the team designed a system for studying the tunneling effect of electrons. In 1984, Binnig became the group leader.

The team's work earned them recognition in the physics community and several awards, including the German Physics Prize, the Otto Klung Prize, the Hewlett Packard Europhysics Prize, and the King Faisal Prize. From this research, Binnig and Rohrer developed the scanning tunneling microscope (STM), which allows scientists to view surfaces at the atomic level. Binnig and Rohrer earned the 1986 Nobel Prize in Physics for this invention. They received the award at a time when the microscope's full spectrum of uses was yet to be discovered; it had been only five years since the microscope was first tested. However, the prize committee expressed confidence in the STM as an instrument that would expand the study of the structure of matter and create new fields of research. Binnig and Rohrer shared the prize with the German scientist Ernst Ruska.

From 1985 to 1986, Binnig was sent to the IBM Almaden Research Center in San Jose, California. Continuing to work with Gerber and also working with Calvin F. Quate, a professor at Stanford University, Binnig invented the atomic force microscope (AFM). This microscope charts surface atomic structure; it accomplishes this by measuring the force acting on the tip of its probe. The tip is made of either ceramic or semiconductor material and is one atom wide. The AFM is able to image, measure, and manipulate matter at the nanoscale. In 1987, Binnig was appointed an IBM fellow and became head of the IBM physics group at the University of Munich. From 1987 to 1988, he was a visiting professor at Stanford University.



Gerd Binnig. (©The Nobel Foundation)

While devoting his time primarily to scientific research in the field of physics, Binnig continued to value imagination and philosophy. In 1989, he published *Aus dem Nichts* (out of nothing), in which he explored the relationship of human creativity and chaos. He proposed that human creativity results from disordered thoughts. In 1990, he began to pursue an interest in politics and became a member of the board of the Daimler-Benz holding company.

In 1994, Binnig founded his own company, Delphi Creative Technologies, in Munich to develop knowledge-based systems. He held the positions of chief researcher and scientific coordinator and led his research team to design a technology that closely replicates human thought patterns, called Cognition Network. The company was renamed Definiens Cognition Network Technology and eventually became a subsidiary of Definiens AG. In 1995, Binnig resigned as head of the IBM physics group in Munich.

Binnig continued to work at the IBM research laboratory in the early twenty-first century. Much of his research has been involved with his theory of "fractal Darwinism," used to describe complex systems. In 2003, he presented the plenary lecture at the Electrochemical Society meeting in Paris. In his lecture, he discussed the IBM project Millepede, which is concerned with increasing the density of data storage capacity.

IMPACT

With the invention of the scanning tunneling microscope in collaboration with Heinrich Rohrer and the invention of the atomic force microscope in collaboration with Christoph Gerber and Calvin Quate, Binnig made a significant impact on the world of scientific research. These microscopes played a key role in the emergence of nanoscience and significantly expanded research possibilities in a wide variety of fields, including chemistry, physics, medicine, bioengineering, and microelectronics. With the STM and the AFM, researchers can image materials that are electrically conductive or nonconductive and can see individual atoms. Binnig's work in complex knowledge-based systems and nanomechanical systems of data storage have opened up new possibilities for creating tools and systems capable of addressing the needs of a social system based on a global information network.

—*Shawncey Webb*

THE SCANNING TUNNELING MICROSCOPE

The scanning tunneling microscope (STM) was invented in 1981 by Gerd Binnig and Heinrich Rohrer at the International Business Machines (IBM) Research Laboratory in Rüschlikon, Switzerland. Both Binnig and Rohrer had been engaged in research on superconductivity. Starting from this common interest, they began to study and explore the surfaces of materials.

At first, they used spectroscopy, which measures the interaction of radiant energy with matter. This technique proved inadequate for revealing the complex characteristics of a surface. While doing research on superconductivity as a graduate student, Binnig had examined tunneling, a phenomenon of quantum mechanics. Tunneling occurs when electrons, because of their wavelike makeup, escape from the surface of a solid and create an electron cloud around the solid. Binnig and Rohrer knew that electrons are capable of tunneling through clouds, which touch and overlap between surfaces. (Ivar Giaever had proven this in 1960.)

Binnig and Rohrer proceeded to cause electrons from a solid surface to tunnel through a vacuum to a sharp probe resembling a needle. In their experiment, they brought the tip of the probe to within one-billionth of a meter (one nanometer) of the solid surface, causing the electron clouds of the probe and the surface to touch and a tunneling current to begin to flow. In order to create a three-dimensional map of the surface, atom by atom, it was essential that the probe follow the tunneling current at a constant height above the atoms of the surface. To maintain this height, the probe had to be isolated from vibration and noise, both of which caused serious problems. To solve these issues, Binnig and Rohrer devised a number of technical innovations, including a probe tip that was one atom wide.

As Binnig and Rohrer used the scanning tunneling microscope to explore many different surface structures, including that of deoxyribonucleic acid (DNA), and to observe the interaction of chemicals, the value and importance of the microscope became more and more apparent. Using the STM, Binnig himself actually saw a virus escape from a cell; it was the first time anyone had witnessed this happen. The STM was the first microscope capable of imaging individual atoms. In 1990, a team of researchers at the IBM research laboratory succeeded in moving and rearranging individual atoms. The scanning tunneling microscope is readily applicable in a number of fields. The work of chemists, physicists, bioengineers, and medical researchers has been enormously enhanced by the STM.

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Shorte, Spencer L., and Friedrich Frischknecht, eds. *Imaging Cellular and Molecular Biological Functions*. New York: Springer, 2007. Good selection of essays on imaging, and its development and application. Discusses the Definiens Cognition Network and Binnig's work.

See also: Sumio Iijima; Heinrich Rohrer; Ernst Ruska.

CLARENCE BIRDSEYE

American industrialist and naturalist

Birdseye is best remembered for his contributions to food preservation and processing. Although his name is usually associated with the freezing of food, he also perfected means of dehydrating food and preserving it in other ways.

Born: December 9, 1886; Brooklyn, New York
Died: October 7, 1956; New York, New York
Also known as: Clarence Frank Birdseye II (full name)
Primary fields: Food processing; packaging
Primary invention: Quick freezing

EARLY LIFE

From childhood, Clarence Frank Birdseye II was fascinated by nature. At age five, he preserved the skin of a mouse, proudly presenting it to his mother as a gift. Born in Brooklyn, New York, to Clarence and Ada Underwood Birdseye, Clarence had two consuming passions: natural history and food.

Before Birdseye was a teenager, his family moved to Montclair, New Jersey. Here, part of Birdseye's destiny unfolded when he enrolled in a cooking class at the local high school. He had already become such a proficient taxidermist that he ran advertisements in a sporting magazine announcing his availability for teaching the art of animal preservation, showing early signs of the business astuteness that was to mark his later life. He named his company the American School of Taxidermy.

Following high school, Birdseye enrolled in Amherst College as a biology major. Financial pressure forced him to work in order to earn money to finance his education. He worked and continued as a full-time student for two years, partly by raising and selling to the Bronx Zoo frogs that would be used to feed many of the zoo's snakes. He trapped and sold over one hundred specimens of black rats to a Columbia University professor for use in breeding experiments the professor was conducting. These enterprises earned him the nickname of "Bugs" among his friends and classmates.

Clarence Birdseye. (Getty Images)

Despite his efforts to sustain himself and continue his schooling, Birdseye finally realized that his attendance was irregular because of the pressure to earn money and that his college career was being severely compromised by his need to support himself and struggle to pay his tuition. On completing his sophomore year, he withdrew from Amherst.

After working in New York City for a while, Birdseye was hired by the U.S. Department of Agriculture in 1910 as a field naturalist, a position that led to the publication of his monograph, *Some Common Mammals of Western Montana in Relation to Agriculture and Spotted Fever*, which appeared in 1912. In his job as a field naturalist, Birdseye traveled through much of the American Southwest. He began a fur-trading business that he quickly turned into a moneymaking enterprise.

The success of this venture caused him to go to Labrador in 1912 with the medical missionary Sir Wilfred Grenfell to engage more fully in the fur trade. He remained in Labrador for the next five years, but his time there ended with the entry of the United States into World War I in 1917.

LIFE'S WORK

During a holiday in the United States in 1915, Birdseye married Eleanor Gannett. He returned to Labrador alone because his wife was pregnant, but after the birth of the child, Eleanor and the infant went to Labrador with Birdseye. The couple would have three more children. Now with family responsibilities, Birdseye needed to provide for his family in Labrador's harsh and inhospitable climate. In particular, he had to be sure that they had enough to eat.

The beginning of Birdseye's experiments in freezing food came about when he observed that the Labrador natives, when they pulled fish from the water and laid it on the ice, ended up with solidly frozen fish that, if kept frozen, could be thawed and cooked weeks or even months later. Fish preserved in this way tasted as good as they would have on the day they were caught as long as they were solidly frozen until they were cooked.

Birdseye also observed that fish caught in the height of the winter, when temperatures approached –50° Fahrenheit, tasted better when they were finally cooked than similar fish that had been caught in the autumn and frozen more slowly when temperatures, although still well below freezing, were higher. He concluded that the secret to keeping frozen food as fresh as possible depended upon what he termed "quick freeze."

Experimenting with various methods of freezing food, Birdseye was able to preserve not only fish, seafood, and meat but also vegetables that grew profusely in Labrador's sunlit summer and that could be frozen when the temperatures sank. He was able to feed his family well with the food he froze.

Although he may not have understood fully the theoretical aspects of what he was doing, Birdseye's method of quick freezing preserved the freshness of food because it did not allow large ice crystals to form in it. Had these crystals formed, they would have altered drastically the cellular structure of the food being preserved, thereby reducing its flavor and texture as well as its vitamin content.

Birdseye spent two years, 1917 to 1919, as a purchasing agent for the United States Housing Corporation. He then became assistant to the president of the United States Fisheries Association, serving from 1920 until 1922. His interest in freezing food grew. In 1923, he set up shop in the periphery of an ice house in New Jersey and, with capital of seven dollars, continued his experiments. These experiments led him to the discovery that fish packed in boxes could be frozen rock-solid and preserved effectively.

He found that perishables could be quick-frozen by pressing them between belts that permitted a heat exchange between the belts—later replaced by refrigerated metal plates—and the food to be frozen. The only problem was that once the food was frozen, it had to be preserved in freezers, so the notion of selling frozen food in typical markets seemed impossible.

Not to be daunted, Birdseye, who by now had established the General Seafood Corporation with the aid of some affluent partners, demonstrated his exceptional acumen as a businessman. He persuaded executives at the American Radiator Corporation to manufacture display units that would preserve frozen foods at temperatures low enough to keep them solidly frozen. He then prevailed on this company to lease these display units to grocery stores for eight dollars per month.

Once this accord was reached, the mass sale of frozen foods was just a matter of time. The first sale of frozen foods on a retail basis occurred on March 6, 1930, in Springfield, Massachusetts. During the next fifteen years, frozen food ceased to be a novelty and became a necessity for many people who now could buy the ingredients for entire meals in frozen form and prepare them for use in a short time, a definite boon to the working women much in evidence during World War II.

In 1944, Birdseye expanded his business by leasing insulated railway cars that could transport his goods anywhere in the nation. The following year, airlines began to stock frozen dinners to serve to passengers, and by 1954, the so-called TV dinner appeared in stores.

On August 12, 1930, Birdseye received a patent for his "double-plate" method of freezing food, one of over three hundred patents he was granted during his life. This method involved placing food in cartons that were then frozen between two flat, refrigerated surfaces under pressure.

In 1929, the Postum Company, skilled at marketing food products, and the Goldman Sachs Trading Corporation bought Birdseye out for just under $25 million, an almost unimaginable amount at that time. Ever ambitious, the newly minted millionaire continued to work on food preservation and developed a method of dehydration known as the anhydrous method. He also invented and patented an infrared heat lamp and a recoilless harpoon gun.

In 1953, at age sixty-seven, Birdseye embarked on a two-year venture in Peru, where he worked on developing a process using the waste product of sugarcane, bagasse, to make paper stock. Peru's high altitude affected him adversely and possibly contributed to the heart problems that took his life on October 7, 1956.

QUICK FREEZING

When Clarence Birdseye perfected his method of quick freezing, the frozen food industry was on the road to becoming the behemoth it has grown into. Earlier experiments with freezing foods involved slow freezing, in which a significant loss in flavor occurs and in which vitamins and minerals are diminished. Quick freezing overcomes these difficulties.

The most common form of quick freezing is the air-blast method, in which food is subjected to a steady blast of air chilled to about –50° Fahrenheit. This air is forced into an insulated tunnel through which food passes on a conveyor belt. Generally the food has already been packaged, although sometimes fruits and vegetables are frozen before packaging. This method of freezing is in common use because it is relatively inexpensive and produces dependable results.

Also in common use is the indirect-contact method, in which packaged foods are placed between metal plates that have been chilled to about –28° Fahrenheit. As these sheets absorb heat from the food packages, the contents of the packages are frozen solid.

A more dramatic result is achieved through nitrogen freezing, which uses liquid nitrogen under pressure. At –280° Fahrenheit, liquid nitrogen is vaporized. The vapor is then forced into a chamber where it freezes food almost instantly. Although this method of quick freezing is highly effective, its use is limited because it is considerably more expensive than the two methods discussed above.

Even more expensive than nitrogen freezing is dry-ice freezing that uses powdered dry ice rather than nitrogen. The dry ice vaporizes very quickly and immediately freezes the food that is exposed to it. Despite the effectiveness of this method, it is seldom used because of the cost.

A final method, liquid-CFC freezing, involves spraying or dipping into liquid chlorofluorocarbons (carbons that contain carbon, chlorine, and fluorine) food that is to be frozen. Because CFCs are environmentally harmful, their production in the United States has been banned since 1956, forcing food processors to rely on one of the four alternate methods for quick freezing.

IMPACT

It is difficult to conceive of a modern food event with the far-reaching consequences of the frozen food industry, which as early as 1976 had turned into an enterprise that brought over $17 billion into the U.S. economy annually. Almost every home in the United States has a refrigerator with a frozen food compartment with a constant temperature around zero. Many homes have deep freezes as well for storing large quantities of food for long periods of time.

The Food and Drug Administration has acknowledged that quick freezing preserves the vitamin and mineral content of foods. It is possible to ship frozen foods anywhere to feed people who might otherwise have diets deficient in the beneficial elements found in fresh food. In the contemporary United States, where both parents in typical families work, frozen food has become a necessity because of its variety and ease in preparation.

In 2005, the National Inventors Hall of Fame posthumously elected Birdseye to membership for the impact his work has had on American society. This prestigious organization recognizes people whose work has altered society and enhanced the lives of Americans.

—*R. Baird Shuman*

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See also: George Washington Carver; John Harvey Kellogg; Henri Nestlé.

KATHARINE BURR BLODGETT

American physicist and chemist

Working with thin films of fatty acids deposited on glass, Blodgett was able to build up more than two hundred successive layers. In a series of studies, she developed important applications for these films.

Born: January 10, 1898; Schenectady, New York
Died: October 12, 1979; Schenectady, New York
Primary fields: Chemistry; physics
Primary inventions: Langmuir-Blodgett films; nonreflecting glass

EARLY LIFE

Katharine Burr Blodgett was born in Schenectady, New York, on January 10, 1898. Her attorney father, George Bedington Blodgett, was head of the patent department at the world-class research laboratories of the General Electric Company (GE). Since Mr. Blodgett had died a few weeks before Katharine's birth, she was raised by her mother, Katharine Buchanan Blodgett, née Burr. The family, including her older brother, moved to New York City and later to Europe, where the children became bilingual and were exposed to French culture. The Blodgetts returned to New York briefly, and Katharine studied for a short time at an American school in Saranac Lake. Following further European travels, chiefly in Germany, Katharine completed her early education at the Rayson School in New York City.

At the age of eighteen, Blodgett earned a scholarship to Bryn Mawr College. She excelled in physics under James Barnes and mathematics under Charlotte Agnes Scott. In interviews later in life, Blodgett recognized these two teachers as making important contributions to the atmosphere that challenged her mind. In 1917, she received her bachelor's degree and went to the University of Chicago, where she studied the adsorption of gases on charcoal. After World War I, this work was published jointly with her mentor Harvey B. Lemon.

Prior to her studies at Chicago, Blodgett visited the General Electric laboratories at Schenectady and was guided around by Irving Langmuir, her father's colleague and the future Nobel laureate in chemistry. He recognized her talent and perhaps suggested that she might become his assistant after acquiring more scientific background. After completing her master's degree at Chicago, she joined Langmuir as the first female scientist at GE. There followed six years of productive collaboration.

Katharine Burr Blodgett. (Library of Congress)

Langmuir appreciated what a talented associate he had found in Blodgett, and she realized that her career would be severely limited without a doctorate. With his help, she was accepted at Cambridge University in the laboratory of Sir Ernest Rutherford (Nobel laureate in chemistry, 1908). The essential new knowledge contained in her thesis appeared under her own name in the *Philosophical Magazine* in 1926. These studies dealt with the flow of electrons in mercury vapor. In the same year, she became the first woman to be awarded a doctoral degree in physics by Cambridge University.

LANGMUIR-BLODGETT FILMS

In 1934, Katharine Burr Blodgett published a brief "communication" in the *Journal of the American Chemical Society* in which she described a technique for depositing a single layer of fatty acid molecules on glass. The study of these molecular size layers, now known as Langmuir-Blodgett films, constitutes her greatest scientific accomplishment and led directly to several practical inventions. Such molecules possess both a polar, hydrophilic region and a nonpolar, hydrophobic region. The attraction between such pairs of opposite polarity in a single molecule allows the buildup of successive layers on a surface. In addition to glass, she was able to build her films on a variety of metal surfaces.

Using this new technique, Blodgett was able, over the next year, to build up more than two hundred successive layers, and she found that each succeeding layer produced a distinctive interference color. These changes in color allowed her to construct a sensitive instrument for measuring the thickness of each layer of very thin arrays. The utility of her thickness gauge was shown to be between 1 and 100 nanometers, or in the ten millionths of an inch range. Her original gauge, being quite fragile, limited its widespread application. It was converted into a more robust instrument that was quickly marketed by General Electric. What had long been a tedious process of measurement became a simple comparison for determining a film's thickness.

Further research led Blodgett to her most celebrated invention—nonreflecting glass. The popular press universally insisted on calling it invisible glass, and it did transmit 99 percent of light that struck the glass. The technique involved controlling both the thickness and the refractive index of the film layers. She used a mixture of a fatty acid and its barium salt. When the layers formed, they were washed with benzene, and the fatty acid was dissolved, leaving a skeleton film of the salt and air. This approach allowed her to control the refractive index with great precision.

Blodgett continued to make other significant applications of her basic studies. For example, by building up three thousand layers of a mixture of barium and copper salts of stearic acid, she created the first controlled-thickness X-ray "grating." By oxidizing hydrocarbon molecules, she invented an "indicator oil." The invisible film of this product allowed her to add an oil that did not otherwise spread and to control its precise thickness. The material and the technique of using it allows one to detect the edge of invisible films and to demonstrate their optical properties. The scientific importance of Blodgett's research is reflected by her authorship of six U.S. patents.

LIFE'S WORK

When Dr. Blodgett returned to Schenectady, Langmuir, her mentor-collaborator, had begun a series of studies that were to win him the Nobel Prize in Chemistry in 1932. The work concerned the behavior of thin films involving a single molecule in thickness. His studies of the forces of adsorption led to a great improvement in the understanding of the molecular attractions between the phases. For the next six years, she would collaborate with Langmuir, and together they published a series of significant articles in the *Journal of the American Chemical Society* (*JACS*) and the *Physical Review*. Some of these early studies dealt with gases and the properties of tungsten and are clearly related to Langmuir's general interests and his efforts to improve the efficiency of electric light bulbs. In addition to their joint publications in scientific journals, they successfully applied for several patents.

In 1933, when Langmuir returned from Sweden after receiving the Nobel Prize, he asked Blodgett to begin working with him on the behavior of thin films; especially those having a thickness of a single molecule. They were able to develop techniques for the study of solids, liquids, and gases. In time, their work even included the large and complicated proteins. In 1935, they published a paper dealing with "new methods for research with monomolecular films" in the German journal *Kolloid-Zeitschrift*. In 1937, an article appeared in *Physical Review*.

Langmuir had never treated Blodgett as an assistant, and she rewarded his confidence with a scientific life of her own. While making significant contributions to their joint research, she was also striking out on her own. In 1934, she published a work under her own name in the *Journal of the American Chemical Society*. Its title, "Monomolecular Films of Fatty Acids on Glass," foreshadowed much of her future scientific career. In the same year, she reported on interference colors in oil films on water in the *Journal of the Optical Society of America*. In 1935, the same year as her joint study with Langmuir, she returned to the *JACS* with a very long article (sixteen pages) describing her technique in great detail.

For twenty years, until her retirement in 1963, Blodgett continued to perfect her techniques and to devise practical applications for them. Her most celebrated accomplishment was the discovery in 1938 of a nearly nonreflecting glass. An avalanche of popular articles appeared reporting on the woman who invented “invisible glass.” It is instructive to observe just how close the competition is in exciting areas of science: Just two days after Blodgett’s publication, two physicists at the Massachusetts Institute of Technology (MIT) announced that they had produced nonreflecting glass by a completely different process. While neither the GE nor the MIT product was stable enough for most practical applications, it was a short time before others solved the problem by building on Blodgett’s insights. Today, people take for granted the presence of nonreflecting glass in all kinds of optical instruments as well as windshields, picture frames, and eyeglasses.

In World War II, GE contributed to the war effort, and Blodgett worked with Langmuir to develop an improved generator for military smoke screens. The apparatus was a great success and undoubtedly saved many lives in the invasions during the war. Blodgett was among the earliest users of a huge analog computer built by GE. Her calculation of the trajectories of cloud droplets was important in dealing with the critical problem of icing on aircraft wings.

A number of schools awarded Blodgett honorary degrees, including Elmira College and Brown University. The American Association of University Women presented her with its Annual Achievement Award in 1945. In 1951, she received the Garvan Medal from the American Chemical Society. She died in her Schenectady home when she was eighty-one.

IMPACT

The most striking characteristic of Blodgett’s career must be her absolute dedication to science. Rather than seeking professional acclaim and financial advantage, she spent her entire life probing nature’s secrets. As the protégé, and later colleague, of an internationally celebrated scientist, she displayed an independence that was remarkable for her time and is still rare. As a scientist, her career exemplifies discipline, and she truly inspired those with whom she worked. Her ability to turn the highest quality research in pure science into practical products is admirable. Equally remarkable is the rapidity with which her devices became tools that opened exciting new opportunities in pure science.

A little-noticed aspect of Blodgett’s contribution is found in her practical work during both world wars. In the waning years of “the war to end wars,” her research for her master’s degree centered on the adsorption of gases on charcoal. These studies, which sought to lessen the terror of chemical warfare, were not published until after the war. In the 1940’s, Blodgett worked with Langmuir on developing a highly successful smoke generator that served in the invasions of Africa, Sicily, and Normandy. In those same years, she worked on the problems associated with deicing the wings of aircraft.

—*K. Thomas Finley*

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See also: Irving Langmuir; Isaac Merrit Singer.

MARIE ANNE VICTOIRE BOIVIN

French midwife

Boivin was one of the leading midwives and female medical researchers in nineteenth century France. She wrote extensively on gynecological diseases and invented the Boivin bivalve vaginal speculum.

Born: April 9, 1773; Montreuil, near Versailles, France
Died: May 16, 1841; Paris, France
Also known as: Marie Anne Victoire Gillain (birth name)
Primary field: Medicine and medical technology
Primary invention: Bivalve vaginal speculum

EARLY LIFE

Marie Anne Victoire Boivin (mah-ree ahn veek-twahr bwah-van), née Gillain (zhee-lan), was born in 1773 in Montreuil, an eastern suburb of Paris. She received her early education in the arts and sciences from the nuns of the Visitation of Marie Leszczyńska. After the French Revolution broke out in 1789, the sixteen-year-old lived with and studied under an order of nursing nuns in Étampes, roughly thirty miles southwest of Paris. Through a hospital surgeon, Gillain learned about midwifery and anatomy. She lived and worked in Étampes for eight years, gaining much valuable medical knowledge.

In 1797, the twenty-four-year-old Gillain returned to her family’s home in Montreuil. Later that year, she married Louis Boivin, who worked as an assistant in the Bureau of National Domains. Their marriage was to be brief: By the end of 1798, she was left a widow with an infant daughter.

Putting her medical education to work, Boivin sought a position at the Hospice de la Maternité in Paris. This free, government-sponsored maternity facility, recently established in a former abbey, was a teaching hospital that provided care to poor and unwed mothers. The Maternité took Boivin on as a student midwife. There she became an assistant to the midwife in chief and head of practical teaching, Marie-Louise Dugès LaChapelle (today regarded as the mother of modern obstetrics). The Maternité awarded Boivin a diploma in midwifery in 1800.

LIFE’S WORK

After graduating, Boivin worked for a short time as a midwife in Versailles. When her young daughter died in an accident, Boivin ended her independent practice and returned to Paris and the Maternité, where she became supervisor in chief.

Over the next decade, Boivin’s talents grew and flourished at the Maternité. She worked alongside LaChapelle, who was also widowed and supporting herself, and whose obstetrical knowledge was vast. (LaChapelle had assisted her midwife mother as a child, been married to and learned from a surgeon, and studied in Germany, which was renowned for the quality of training afforded its female physicians and midwives.) The Maternité appears to have been a comparatively positive environment for female physicians. The prominent obstetrician heading the Maternité, Jean Louis August Baudelocque, was committed to providing midwives with a quality education, and he was not above respecting or acknowledging the abilities of female colleagues. That said, he ignored LaChapelle’s and Boivin’s opinions regarding the contagion hazard posed by having large groups of onlookers present during births and his liberal use of forceps and other instruments to extract the baby from the birth canal.

In 1812, at the urging of Maternité physician in chief François Chaussier, Boivin published *Mémorial de l’art des accouchemens*, a reference book for midwives, which included more than a hundred of her careful illustrations

The Vaginal Speculum

The vaginal speculum is an instrument that is inserted into the vagina to facilitate visual inspection or medical treatment. By the nineteenth century, the vaginal speculum was hardly new—Greek and Roman writings mention the instrument, and bivalve, trivalve, and quadrivalve models were excavated at Pompeii. (It is unclear whether these were intended as examination and diagnostic tools or a means to hasten labor.)

Centuries later, specula fell into disfavor. The propriety of their use was debated, and—in the case of turnscrew models that required two people to operate them—their awkwardness of operation was daunting for doctor and patient alike. In 1801, French physician and professor of medicine Joseph Récamier repopularized the speculum among medical professionals, using a simple tin tube for vaginal examinations. Marie Anne Victoire Boivin initially used such a speculum.

The instrument that Boivin created in 1825 returned to the old bivalve model, but with improvements. The blades were small and, when closed, formed a slim cone. The overall design was intended to cause as little discomfort as possible. Boivin abandoned the difficult turnscrew mechanism for opening the blades, instead equipping her speculum with rounded, scissorlike handles that spread the blades when squeezed. A screw could be used to widen the handle end of the speculum farther.

Récamier independently developed a similar speculum at about the same time, and both he and Boivin are generally credited with inventing the modern bivalve vaginal speculum. Boivin later improved on her design, devising a speculum in 1836 that had a fenestrated blade to allow inspection of the vaginal wall. A sliding shaft was used to open and close the opening.

Boivin's speculum, coupled with her extensive research and writings, allowed medical practitioners to treat gynecological diseases more effectively. No longer limited to treatments determined by diagnoses based on external symptoms, physicians were able to diagnose with greater accuracy and treat accordingly. Visual examination also helped doctors and midwives develop a better understanding of the female reproductive organs and their pathologies. While Victorian prudery kept use of the speculum from becoming universal in the nineteenth century, it has since been integrated into routine medical monitoring for adult female patients. The speculum used today during regular pelvic examinations and Pap smears is descended from Boivin's invention.

of the fetus in the uterus. The book was in great demand in France and abroad; by 1824, it was in its third edition. However, Boivin's position at the Maternité was terminated around the time of the book's initial publication. Historians have suggested that she and the Maternité parted ways because LaChapelle or male colleagues were jealous of her success.

Boivin went on to become codirector of the general hospital at Seine-et-Oise in 1814. That year, her work was recognized by King Frederick William III of Prussia, who awarded her the Order of Civic Merit. In 1815, she assumed the directorship of a temporary military medical hospital. She later headed the maternity hospital in Bordeaux and the Maison Royale de Santé. In 1818, she translated two important English works on uterine hemorrhage and wrote a comprehensive review of the literature on the subject. Her own book on hemorrhages of the uterus, *Memoire sur les hemorrhagies internes de l'uterus*, won an open competition in 1819 held by the Medical Society of Paris. (The society selected her book as the winner under the mistaken assumption that the author was male.)

In 1827, she published *Nouvelles Recherches sur l'origine, la nature et le traitement de la môle vésiculaire ou grossesse hydatique*, her original research into the hydatidiform mole, a sometime malignant condition in which an abnormal fertilized egg or placental overgrowth mimics pregnancy. Also in that year, the University of Marburg in Prussia conferred upon her the honorary degree of doctor of medicine. The following year, she received a commendation from the Royal Society of Medicine in Bordeaux for her research into miscarriage.

In 1833, she published her most important work, *Traité pratique des maladies de l'uterus et des annexes*. This two-volume treatise on diseases of the uterus listed as its coauthor Antoine Dugès, LaChapelle's nephew and a professor of medicine at Montpellier. The book included the first recorded observation of urethral cancer in a woman. Modern for its time, the treatise was widely used as a textbook in France and beyond. It was translated into English the year after its first printing in France.

Boivin introduced several innovations to the practice of gynecology and obstetrics. After René-Théophile-Hyacinthe Laënnec invented the stethoscope in 1816, Boivin was one of the first to employ it to monitor the fetal heartbeat. She used the vaginal speculum (at the time, a long-neglected instrument experiencing a resurgence) not for obstetrics but for checking the health of the cer-

vix. She also designed gynecological instruments, notably a bivalve vaginal speculum (1825) that was a forerunner of the ones used today, a fenestrated speculum (1836), and an "intropelvimeter" (1828), her improvement on the device commonly used for measuring the diameter of the pelvis. She was one of the first surgeons to excise a cancerous cervix.

During her career, Boivin turned down prestigious offers—including one from Catherine the Great of Russia—instead choosing to continue her work with indigent women. When she retired, she received an exceedingly small pension, reflecting a lifetime of low wages. She died in poverty in 1841 at the age of sixty-eight.

IMPACT

Boivin was one of many women of her time who gained a foothold in the traditionally male world of medicine through the traditionally female practice of midwifery. She was held in high esteem not only by other midwives but also by male colleagues. Guillaume Dupuytren, a well-known surgeon who asked Boivin to deliver his grandchild before her retirement, famously remarked that she worked as if she had eyes at the tips of her fingers. While some all-male professional organizations barred her from their ranks, she was a member of several other medical societies.

Unable to gain admission to mainstream French medical schools, Boivin nonetheless made and publicized important, original medical discoveries. Her use of a stethoscope in obstetric monitoring has become commonplace, as has the employment of a bivalve speculum for vaginal examinations. Hygienic practices she and LaChapelle advocated have also become routine in modern medicine.

Boivin advanced the fields of gynecology and obstetrics, improving the lives and health of women and their babies. Thanks to her many publications, Boivin had an impact on the midwives of her generation and the next, in her own country and beyond. Her influence even reached the New World: Marie Durocher, midwife to the imperial family of Brazil, relied heavily on Boivin's texts.

—*Karen N. Kähler*

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See also: Helen M. Free; René-Théophile-Hyacinthe Laënnec.

H. Cecil Booth

English engineer

Booth invented the first suction vacuum cleaner, a machine that cleaned carpets and upholstery efficiently and without simply blowing dirt, dust, and other debris from one spot to another. The fundamental principles of Booth's invention are still seen in modern vacuum cleaners.

Born: July 4, 1871; Gloucester, Gloucestershire, England
Died: January 18, 1955; Purley, Surrey, England
Also known as: Hubert Cecil Booth (full name)
Primary fields: Household products; manufacturing
Primary invention: Vacuum cleaner

Early Life

Hubert Cecil Booth was born in Gloucester, England, in 1871. One of six sons of a lumber merchant, Booth excelled at all things mechanical. His early schooling was under the direction of the Reverend H. Lloyd Breerton at Gloucester County School and Gloucester College. In 1889, Booth moved to London, where he enrolled at Central Technical College at the City and Guilds College. W. C. Unwin directed his three-year course in civil and mechanical engineering. Booth graduated as the second highest scoring student, obtaining his diploma of associateship. He then enrolled at the Institution of Civil Engineers. Booth became acquainted with Francis Tring Pearce, the director of Priday, Metford & Company, and married one of Pearce's daughters.

In December, 1882, Booth began working for Maudslay, Sons and Field as a drafter. The company was well known in England for its manufacture of engines. Booth initially worked on the design of two Royal Navy battleships, and his talent for designing machinery soon attracted attention; he left Maudslay to join a company that developed the huge wheels of the kind invented by the American G. W. G. Ferris in the 1890's. Steam-operated Ferris wheels were already creating a sensation in Great Britain.

Life's Work

In 1901, at the age of thirty, Booth created his own engineering consulting firm and wanted to manufacture large industrial equipment; he certainly had no thought of creating a small machine that picked up dirt. That machine, the modern vacuum cleaner, was invented almost on a whim. As the story goes, Booth had been invited by a friend to the Empire Music Hall to see a demonstration of an American-made cleaning machine called a mechanical aspirator. The machine, invented by a St. Louis, Missouri, railway worker to clean railway cars, blew compressed air into the carpet from two directions in an attempt to deflect the loosened dirt into a box, creating a

Vacuum Cleaners

The idea of mechanical carpet- and upholstery-cleaning machinery dates from the nineteenth century. In 1869, a dirt-removing machine was created to blow dirt from carpets, but it operated by hand: one person to pump the bellows and the other person to point the nozzle at the floor. Most significant, the debris was blown in the air and thus was not removed completely. Gradually, human power was replaced by either coal or petroleum-powered machines, but they, too, operated by blowing air through and around dirty carpets.

H. Cecil Booth's cleaner used a machine to create a vacuum that sucked dirt and dust out from carpet and upholstery, conveying the debris through a flexible tube into a chamber closed off by a filtering device. This is the essence of Booth's invention, and the basic principle is still used in today's vacuum cleaners. The machine creating the vacuum was powered by a gasoline engine and was so large that it had to be transported on a horse-drawn cart.

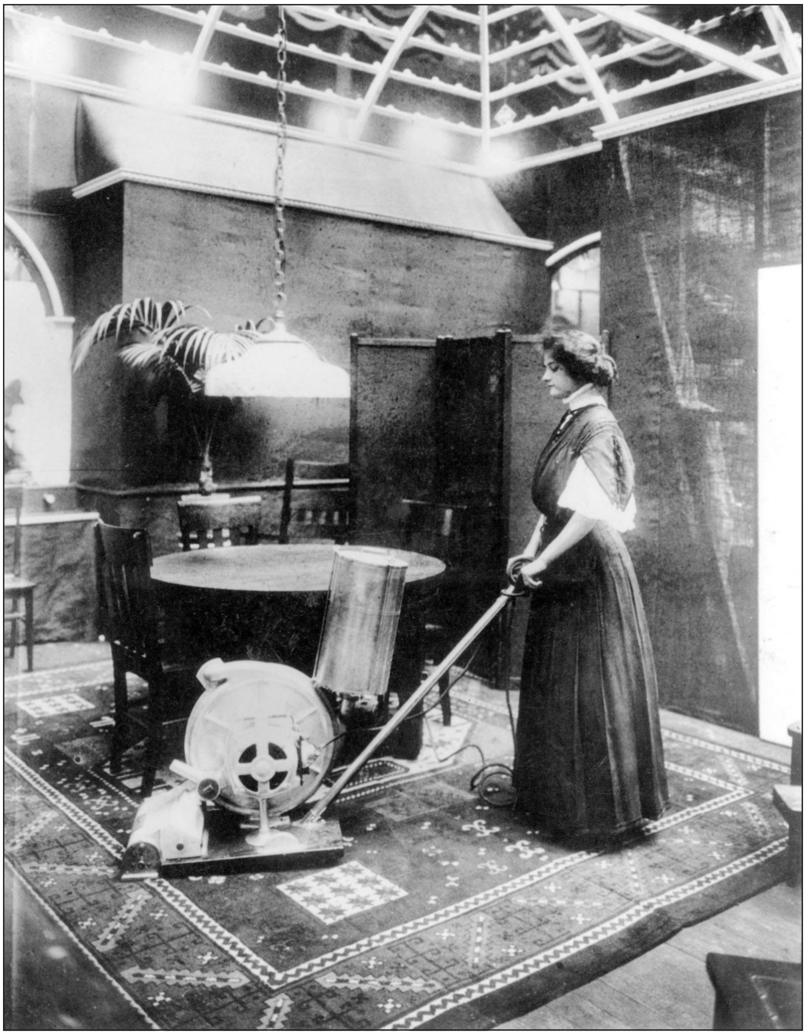
As electricity became more readily available in homes, Booth invented an electric motor to create the vacuum. This motor was much smaller and more efficient, making the product even more cost efficient. By 1926, Booth was able to market this machine under the product label Goblin. Other inventors soon introduced the use of rollers with bristles attached to the machine to loosen the dirt. The same motor that created the vacuum turned the roller by means of a belt.

In the United States, inventors using Booth's design made a number of variations familiar to homemakers and cleaning services. The Hoover Company developed the idea of mounting the bag for the debris on a stick or handle and added wheels that made it possible to wheel the vacuum cleaner around a room. The Electrolux Corporation chose to mount a canister for the dirt on sled-like skids, which could be dragged behind the operator who vacuumed up the dirt with a nozzle attached to a hose. All used Booth's basic idea of a motor to create the vacuum, a filter to capture the dirt, and a container for the debris.

large cloud of dust, most of which settled back into the carpet. Booth wondered if suction could be used instead. He pondered the problem for several days and devised experiments.

Booth was convinced that suction would work. One of his experiments involved placing a wet handkerchief over an upholstered chair at home and sucking on it to draw a large amount of dust into the cloth. He later demonstrated a similar method for his friend in a restaurant (and even choked on the dust he sucked up). He then built a large machine, which he called a Puffing Billy, which was powered by a gasoline engine and pulled on a horse-drawn cart. A suction pump was attached to a hollow tube connected by a flexible hose at one end and a filter at the other. Booth patented his device on August 30, 1901.

Before attempting to sell his new invention, Booth demonstrated its operation before audiences. In one case, he persuaded a restaurant owner to clean a dining room in front of a crowd. The demonstration was successful and word spread rapidly; the device eventually came to the attention of the British royal family. Booth was invited to clean the large blue carpets used at Westminster Abbey for the coronation of King Edward VII in 1902. Later that year, King Edward arranged for a demonstration for himself and the queen. One of the machines was purchased for use at Windsor Castle. Booth also demonstrated his machine for the French president, the German kaiser, and the Russian czar. Booth also gave a demonstration at the Royal Mint.


A British woman uses a vacuum cleaner of 1910. (Popperfoto/Getty Images)

In 1903, Booth created the Vacuum Cleaner Company Limited, a cleaning service that later merged with his engineering consulting firm. The vacuum itself, however, was center stage at the homes of wealthy families, who invited friends to their homes to see the machine in operation. Booth operated the cleaning service for the first few years, charging his clients the equivalent of the annual salary of a chambermaid. His profits were reduced, though, after he had to pay fines for a range of infractions, including blocking traffic and frightening the horses of taxi operators with the horse-drawn cleaning machine. Finally, in 1907, he developed a portable machine small enough to be sold to individuals. In 1926, he began marketing all his machines under the trade name Goblin, a name derived from a chance comment by the wife of an associate, who said the vacuum was "'goblin' up the dirt."

Booth was forced to defend his patent against a number of claimants but won all suits for patent infringement; he even was paid for his legal defense. Later in life he wrote an article on his invention, "The Origin of the Vacuum Cleaner" (1934-1935), which was published in *Transactions of the Newcomen Society*.

IMPACT

By today's standards, it is difficult to understand why those who created carpet and upholstery cleaning equipment did not think of using suction to eliminate dust and dirt instead of attempting to blow it away. Booth's invention, patented in 1901, now seems so simple.

Decades later, Booth's machine was made smaller and was eventually powered by electricity (although the usefulness of an electric carpet-cleaning machine depended on the widespread use of electricity). Eventually, the machine included a roller bar with a brush, which loosened the dirt and dust, making it easier for the machine to suck up the debris. Booth did not invent these later devices, but his basic concept for a vacuum set this entire industry in motion.

—Richard L. Wilson

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See also: James Murray Spangler.

CARL BOSCH

German chemist and engineer

Bosch led the group of scientists and engineers who took the ammonia synthesis invented by Fritz Haber (1868-1934) and Robert Le Rossignol (1884-1976) and developed it from laboratory-scale to industrial-scale production during the years 1909-1913. New techniques for high-pressure chemical reactions were invented, and the ammonia production revolutionized agriculture.

Born: August 27, 1874; Cologne, Germany
Died: April 26, 1940; Heidelberg, Germany
Also known as: Karl Bosch
Primary fields: Agriculture; chemistry
Primary inventions: Haber process; gasoline synthesis

EARLY LIFE

Carl Bosch (BOSH) was born in Cologne, Germany, the eldest son of Paula and Karl Bosch. Young Carl's father had come to Cologne from the south of Germany near Ulm and operated a successful plumbing business. Carl's uncle Robert (his father's brother) established a company (still in existence) that manufactures automobile parts and tools. As a youth, Carl developed a wide interest in science, collecting mineral specimens as well as plants and insects. He worked in his father's shop, developing skill with tools, and did chemical experiments in a small home lab. Upon graduation from the *Oberrealschule* (German equivalent of high school), Bosch became an apprentice in a foundry called Marienhütte in the town of Kotzenau. Here he became familiar with metallurgy and metalworking equipment.

Entering the Technische Hochschule in Berlin-Charlottenburg, he studied chemistry and engineering for two years, after which he moved to the University of Leipzig, where he was awarded the Ph.D. degree, summa cum laude, in 1898, and stayed on for a time as assistant to Johannes Wislicenus (1835-1902), who had directed his doctoral research.

Bosch's doctoral thesis was in the field of organic chemistry and concerned a study of a reaction of acetonedicarboxylic acid and diethyl ester. In 1899, Bosch went to work for the chemical firm Badische Anilin- und Soda-Fabrik (BASF). His initial assignment was in connection with the production of synthetic indigo, under the direction of Rudolf Knietsch (1854-1906).

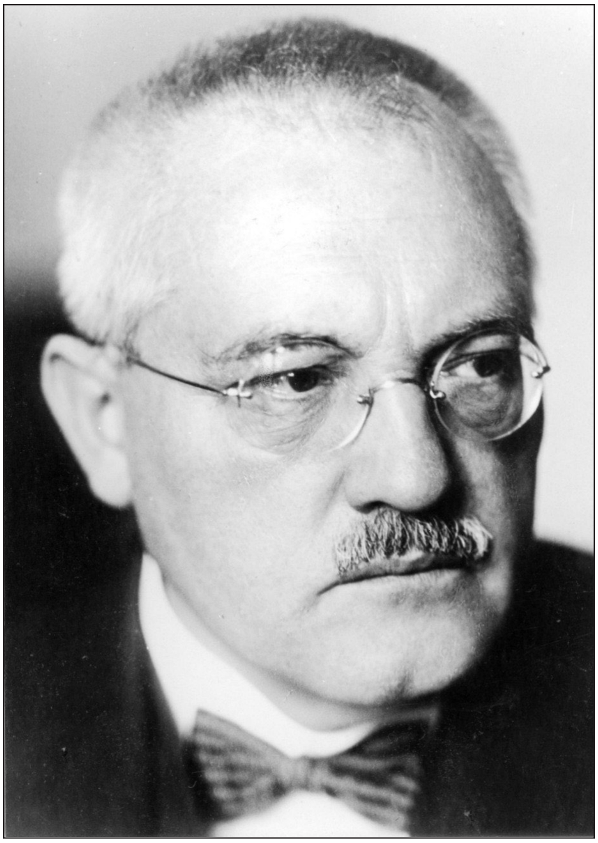
LIFE'S WORK

Bosch began his industrial career in Ludwigshafen, where he improved the process for making phthalic anhydride (a chemical precursor for the alkyd resins used in paint). Later, he reinvestigated some work done by Wilhelm Ostwald (1853-1932) on catalysis of the ammonia equilibrium. In this investigation, he found that Ostwald's results were in error.

Continuing research on nitrogen fixation, Bosch studied the formation of cyanides and cyanamides from reactions of carbides with nitrogen. Calcium cyanamide is able to react with steam to form ammonia, and this process was used for manufacturing ammonia.

Beginning in 1909, Bosch worked on scaling up Fritz Haber's ammonia synthesis. The result was that after a remarkably short time of four years, BASF had developed and brought onstream a synthetic ammonia plant at Oppau (near Ludwigshafen) in 1913. In 1917, a second, larger plant was opened at Leuna (near Leipzig). These plants supplemented the ammonia produced from the cyanamide process and helped to reduce Germany's dependence on imported nitrates from South America. After the start of World War I, the ammonia became a vital raw material for the production of nitric acid, and hence the explosives like TNT (trinitrotoluene) and cordite, for which nitric acid is needed.

Bosch was promoted to managing director at BASF in 1919, and when Interessen Gemeinschaft Farben (I. G. Farben) was founded in 1925, he became a director there. I. G. Farben was organized as a chemical cartel to market and control prices of chemical products, mainly dyes. (The German word *färben* means "dye.") At the end of World War I, the victorious Allies, particularly France, were concerned that a resurgent Germany would become warlike again. The Versailles treaty imposed monetary reparations on Germany, and attempts were made to obtain the technical details of Bosch's ammonia and nitric-acid processes and to accomplish the destruction of the Oppau plant. Bosch was a delegate to the treaty negotiations and was able to head off the French plans to destroy the Oppau works. Ironically, the plant vanished in a gigantic accidental explosion in 1921 that destroyed the town and resulted in six hundred fatalities. Bosch organized the rebuilding of the facilities, which was accomplished in three months with the aid of ten thousand workers.



Carl Bosch. (© The Nobel Foundation)

In addition to ammonia and nitric acid, Bosch was involved in taking the coal hydrogenation process of Friedrich Bergius (1884-1949) from pilot plant to large-scale production. In 1925, Bergius sold the rights of the method to BASF. The process at that stage had a number of shortcomings that were corrected by Bosch and his associates. Bergius had accomplished coal hydrogenation in one step, combining crushed coal with heavy oil or pitch and subjecting the mass to high-pressure hydrogen

THE HABER PROCESS

Fritz Haber demonstrated the ammonia synthesis in Karlsruhe in the presence of Carl Bosch and Alwin Mittasch on July 2, 1909. Haber's apparatus produced 100 milliliters of liquid ammonia that day, operated at a pressure of 200 atmospheres and a temperature of 500°-600° Celsius, and involved a 0.75-meter-tall reactor.

Bosch and his coworkers at Badische Anilin- und Soda-Fabrik (BASF), having acquired the rights to develop the process, immediately tried to scale up to an industrial-sized apparatus. They needed to solve at least three problems: First, they needed a supply of pure hydrogen (nitrogen was readily available from liquid air); second, they had to find a suitable catalyst; third, they needed a technique for handling hydrogen-nitrogen mixtures at high temperatures and pressures. In the succeeding three years, these difficulties were overcome, in part, through inventions by Bosch.

The hydrogen needed was initially obtained by electrolysis, but later it proved less expensive to use the water-gas reaction. Steam reacted with red-hot coke, giving a mixture ("water gas") of carbon monoxide and hydrogen. A catalyzed "shift reaction" allowed the carbon monoxide to react with more steam to form additional hydrogen and carbon dioxide. To purify the hydrogen, the carbon dioxide and residual carbon monoxide were removed by scrubbing with water and copper formate solution.

The catalysts used by Haber for ammonia synthesis were rare metals (osmium and uranium) too costly to use on an industrial scale. The BASF chemists, led by Mittasch, conducted thousands of experiments to discover a cheap, effective catalyst. Their eventual choice was an iron catalyst containing small amounts of iron oxide and other metal oxides.

The early attempts to scale up the ammonia synthesis resulted in catastrophic failure of the steel reactors after about eighty hours of operation. Metallographic examination showed cracking of the metal caused by exposure to high-pressure hydrogen. The carbon steel used in the reactor was vulnerable because of its carbon content. The carbon in the metal could slowly react with high-pressure hydrogen, forming hydrocarbon gases that forced the metal apart, creating cracks. Pure iron was unaffected.

Bosch solved the hydrogen embrittlement problem by an ingenious invention. By lining the inside of the reactor with soft iron, it was possible to circulate the high-pressure gases over the catalyst in such a manner as to prevent them from contacting the carbon steel containment vessel. Cool gas was circulated between the walls and the inner liner.

Bosch also supervised the design of pressure-, flow-, and temperature-recording instruments that enabled close control of the reaction conditions. These instruments are the ancestors of those used in all modern high-pressure industrial processes.

The reactor size was steadily increased over the period 1909-1915. The largest reactor was 12 meters long, 1.08 meters in diameter, and weighed 75 tons. The ammonia plant at Oppau began production late in 1913, and soon was fixing 20 tons of nitrogen per day. Ammonia became a major source of profits for BASF. Converted to ammonium sulfate fertilizer, ammonia relieved Germany from dependence on imported nitrates. Oxidation of ammonia (Ostwald process) afforded a route to nitric acid needed for making explosives.

in a long horizontal reaction vessel. After the reaction, products were separated from residual ash and fractionated. Bergius had not had the facilities to explore possible catalysts for the reaction, nor had he conducted the reaction in two stages, which the I. G. Farben chemists now found beneficial, separating the hydrogenation and cracking aspects and conducting the latter in the vapor phase. These improvements enabled I. G. Farben to manufacture synthetic gasoline at its plant in Leuna in ever-increasing amounts. As Bosch moved into administration, he had less engineering work to do but was active in negotiations with Bergius and in persuading the other directors to persist with the very expensive coal hydrogenation program. In 1935, Bosch became chairman of the board of directors at I. G. Farben. In this position, he traveled to foreign countries, including the United States, to negotiate commercial agreements for oil and coal hydrogenation.

Beginning in 1933, the rise of Adolf Hitler and the Nazis to political power in Germany began to have an impact on all aspects of life. Bosch opposed the anti-Semitism of the regime and tried to help some of the non-Aryans who had lost their positions and wanted to leave Germany. For example, he tried to obtain an exit visa for the physicist Lise Meitner (1878-1968), who wanted to immigrate to Denmark. Such an undertaking on his part was not without personal risk, because of the extreme suspicion of the Gestapo.

In 1937, Bosch succeeded Max Planck as the president of the Kaiser-Wilhelm Institute, Germany's most important scientific society, and left I. G. Farben. Over the next three years, culminating in his death in 1940, Bosch became increasingly pessimistic about the future of Germany and increasingly a user of drugs and alcohol.

IMPACT

In 1931, Bosch and Bergius shared the Nobel Prize in Chemistry for their achievements in developing high-pressure methods. The synthetic ammonia industry pioneered by Bosch and Haber made nitrogen fertilizer available in hitherto unimaginable quantities and made possible the harvests of wheat and other grains to feed the world.

Within a few years, the Haber-Bosch process was implemented around the world, and today ammonia is produced in eighty countries in amounts that approach 140 million metric tons annually. High-pressure techniques, as perfected by Bosch and others, are used routinely in the modern chemical process industries. On a more somber note, it is likely that Germany in 1914-1918 could not have waged war as long as it did without the explosives made possible by the ammonia and nitric-acid syntheses, and conventional modern warfare is equally dependent on the manufacture of these chemicals.

—*John R. Phillips*

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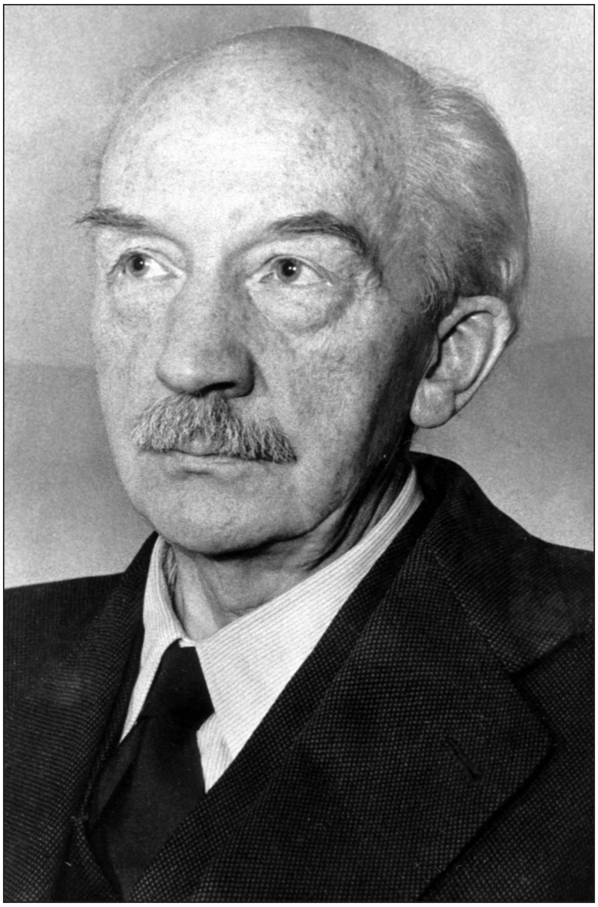
See also: Friedrich Bergius; Fritz Haber.

WALTHER BOTHE

German physicist

Bothe developed the device and method that made possible the coincidence method of particle detection, a crucial step in the development of nuclear physics. He also helped build Germany's first cyclotron, one of the world's first particle accelerators for conducting nuclear research.

Born: January 8, 1891; Oranienberg, Germany
Died: February 8, 1957; Heidelberg, West Germany (now in Germany)
Also known as: Walther Wilhelm Georg Bothe (full name)
Primary fields: Military technology and weaponry; physics
Primary invention: Coincidence method of particle detection



Walther Bothe. (©The Nobel Foundation)

EARLY LIFE

Walther Wilhelm Georg Bothe (VAHL-tuh VIHL-hehlm gay-OHRG BOH-tuh) was born in Oranienberg, a town near Berlin in the eastern part of Germany. After completing his early education in Oranienberg, he entered Frederick William University (later the University of Berlin), where he studied chemistry, mathematics, and physics. His work in physics was most notable, and he became a pupil—and later teaching assistant—to the world-famous physicist Max Planck. After studying there from 1908 to 1912, he joined the Physikalisch-Technische Reichsanstalt (PTR), or Reich Physical and Technical Institute, where he became an assistant to Hans Geiger, the director. In 1914, Bothe completed his doctorate in physics under the direction of Planck; his thesis centered on the molecular theory of refraction, reflection, scattering, and absorption of light rays.

In May, 1914, Bothe joined the German cavalry. When World War I broke out, he served on the eastern front and was captured by the Russians in 1915. He was held prisoner for five years but managed to continue studying and working on theoretical physics. He also learned the Russian language and met a Russian woman, Barbara Below, whom he married before returning to Germany.

LIFE'S WORK

In 1920, Bothe returned to Germany, where he began teaching physics at the University of Berlin. He also accepted an invitation from Geiger to return to PTR, where he served on Geiger's staff until 1927, when he succeeded Geiger as the director of the Laboratory of Radioactivity at PTR after Geiger moved to a new position at the University of Kiel. While Bothe and Geiger worked together, Bothe began work on the coincidence method of particle detection. In 1924, he published on the coincidence method of particle detection and continued his research, applying this method to the study of nuclear reactions, the Compton effect, and the wave-particle duality of light.

In 1925, while still at the PTR, he also completed his habilitation (on gaining tenure at the university) and became a *Privatdozent* (lower-level professor). In 1929, he became an *ausserordentlicher Professor* (mid-level professor), and a year later an *ordentlicher Professor* (full professor) at the University of Giessen. In 1932, he succeeded the Nobel laureate Philipp Lenard as the director of the Physical and Radiological Institute at the University of Heidelberg.

Bothe's rapid rise in the various university ranks suffered a setback in the wake of Adolf Hitler's ascension to power as German chancellor in January, 1933. With Hitler's rise, the anti-Semitic and anti-theoretical physics concept of *Deutsche Physik* (German physics), proposed by Lenard in a book of the same name, gained prominence. The *Deutsche Physik* movement adamantly opposed the "Jewish physics" of Albert Einstein. Since a number of prominent theoretical physicists were Jewish (Bothe was not), all theoretical physicists were persecuted based on guilt by association. Although retired, Lenard had enough power to have Bothe removed as the director of the Physical and Radiological Institute. Bothe threatened to leave Germany altogether as other theoretical physicists had done, but he was persuaded to stay when he was appointed director of the Institute of Physics at the Kaiser Wilhelm Institute for Medical Research in 1934, a position he held until his death in 1957.

Despite this political turmoil, Bothe continued to conduct significant research in nuclear physics. In the late 1920's, he had begun studying the effects of alpha-particle bombardment in the transmutation of light elements. In 1928, he conducted joint research correlating the reaction products of nuclear interactions to nuclear energy levels. By 1929, Bothe had begun work with cosmic radiation, research he continued for the rest of his life. In 1938, he published a paper on the energy dependence of the nuclear photoeffect, and he used a Wilson cloud chamber to begin the work that resulted in the publication of the *Atlas of Typical Cloud Chamber Images* (1940). This book became the widely recognized scientific reference for identifying scattered particles.

Because of their success with the cloud chamber, as well as building a Van de Graaf generator, Bothe and his colleagues began making plans to build a cyclotron, a particle accelerator. Bothe initially encountered difficulties in raising the money but eventually obtained funding once the German military considered a nuclear energy project. Eventually, the government decided that an atomic bomb was not a realistic near-term possibility in World War II and transferred the research back into nonmilitary hands. Nevertheless, the government continued to fund the research.

After Germany conquered France in 1940, the Germans gained control of a cyclotron that the French physicist Frédéric Joliot-Curie was building. Bothe and his colleagues were sent to examine it, and they gained a great deal of knowledge from the French developments. In 1941, Bothe received the necessary funding to build Germany's first cyclotron; in March, 1943, the critical magnet was delivered. By December, the first deuteron

THE COINCIDENCE METHOD OF PARTICLE DETECTION

Since nuclear energy knowledge is pervasive today, it may be difficult to realize that it has been only little over a century since Albert Einstein's first publication of the theory of relativity. Einstein had theorized but not experimentally demonstrated that mass could be converted to energy. To do this required methods for measuring extremely small subatomic particles. Nuclear physicist Walther Bothe was intimately associated with providing the necessary proof. One of Bothe's early teachers, Hans Geiger, created the basic device to measure radioactivity—the Geiger counter—but additional steps were needed to detect and measure particles and the rate of their emission.

More specifically, Bothe sought to show that, when a single portion of an atom passes though two or more Geiger counters, the rate of passage is almost "coincident" in time. The rate of passage, or pulses, is then sent through a coincidence circuit to show that they are coincident in time. Banks of Geiger counters can be used to show small angular variations in the rate of passage of cosmic rays. Bothe applied his method to the study of the Compton effect, for example, whereby high-energy electromagnetic radiation increases in wavelength when it collides with electrons. His demonstration of the small angular scattering of light rays provided strong support for the corpuscular theory of light.

Classical physics held that the energy of incoming X rays ought to equal the combined momentum and energy of the electrons and the scattered X rays after collision. Bothe sought to validate the theories of Einstein and other theoretical physicists that held that the result of the collision was not equal in momentum and energy. To do this, Bothe combined two (or more) Geiger counters with a single amplifier that registered pulses only when particles triggered counters simultaneously. This process, called the coincidence method of particle detection, allowed Bothe to find small-scale variations, a crucial early step in the development of nuclear physics and nuclear energy. For this discovery and other discoveries that followed, Bothe and Max Born shared the 1954 Nobel Prize in Physics.

(a deuterium nucleus) had been emitted. After Germany surrendered in May, 1945, the Allies seized the cyclotron, and Bothe returned to teaching in Heidelberg. The Allies later returned the cyclotron to Bothe, and he continued his research until his death.

During the war, Bothe conducted significant research into the best material to use as a moderator, a substance used for slowing neutrons in a nuclear reactor in order to induce fission. Such research was a necessary step in the creation of an atomic bomb. Bothe's research convinced him that the best moderator would be heavy water—a rare, isotopic form of water that contains deuterium. As a result, the Germans rejected continued research into graphite—a relatively plentiful mineral—as a possible moderator. Unbeknownst to the Germans, Italian American physicist Enrico Fermi, working for the Allied nuclear effort, reached the opposite conclusion and successfully created the first self-sustaining nuclear reactor at the University of Chicago in December, 1942. Fermi's successful research resulted in the first atomic bomb being developed in 1945, while Bothe's conclusion led the Germans on a wild-goose chase. With heavy water as a moderator, the bomb would be twice as difficult to build since two rare substances (heavy water and uranium 235) were needed for a nuclear weapon.

Regarding his work in attempting to develop nuclear energy (and potentially the atomic bomb) for Germany during World War II, Bothe was a patriotic German who did not apologize for his research. However, his dissatisfaction with National Socialist policies led to his being suspected of disloyalty and investigated by the Gestapo.

IMPACT

Bothe's research in the 1920's was an absolutely essential early step toward the development of nuclear energy and the atomic bomb, although the British and Americans were able to exploit this development, while the Germans were not. Bothe, along with the German-born British scientist Max Born, received the 1954 Nobel Prize in Physics as a result of their research. Bothe was close to the center of nuclear physics research for most of his professional life. His single biggest professional misjudgment—favoring heavy water over graphite as a nuclear reactor moderator—was a critical factor in Germany's failure to develop the atomic bomb during World War II, a fact for which many in the world are grateful.

—*Richard L. Wilson*

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See also: Enrico Fermi; Hans Geiger; Ernest Orlando Lawrence; M. Stanley Livingston; J. Robert Oppenheimer.

HERBERT WAYNE BOYER

American biochemist

Boyer, along with Stanley Norman Cohen, developed the basic techniques used in genetic engineering. Boyer and Cohen were the first to use restriction endonucleases to cut DNAs from two different sources, splice them together to make a recombinant DNA molecule, and express the recombinant DNA molecule after insertion into E. coli *cells.*

Born: July 10, 1936; Derry, Pennsylvania
Primary fields: Biology; genetics
Primary inventions: First recombinant DNA organism; human insulin

EARLY LIFE

Herbert Wayne Boyer was born in 1936 in the western Pennsylvania town of Derry. After graduating from Derry High School, where he played football, Boyer commuted to St. Vincent College in Latrobe, Pennsylvania, where he majored in premed biology, receiving a B.S. in biology and chemistry in 1958. He then attended graduate school at the University of Pittsburgh. In 1959, he married Marigrace Hensler. Boyer completed his Ph.D. work in 1963, after which he did three years of postgraduate work focusing on biochemistry at Yale University in the laboratories of Edward Adelberg and Bruce Carlton. While conducting postdoctoral research, Boyer was active in the Civil Rights movement.

LIFE'S WORK

In 1966, Boyer accepted an assistant professorship of biochemistry and biophysics at the University of California, San Francisco (UCSF). His research focused on the isolation and characterization of *Eco*R1, a restriction endonuclease enzyme from *Escherichia coli* (*E. coli*) that cuts molecules of deoxyribonucleic acid (DNA) at very specific nucleotide sequences. Boyer discovered that *Eco*R1 creates DNA molecules with short (four-nucleotide), single-stranded, complementary, "sticky" overhang ends.

In 1972, Boyer teamed up with Stanley Norman Cohen, a professor, research scientist, and physician at Stanford University who had been studying the insertion of small, circular, nonchromosomal DNA molecules called plasmids, which reside and replicate in a variety of bacteria, into *E. coli*. Cohen had realized that two DNAs cut with Boyer's *Eco*R1 restriction endonuclease could easily be spliced together because of the complementary overhangs. In 1973, Boyer, Cohen, Annie Chang, and Robert Helling cut, combined, and ligated two different plasmids and inserted them into *E. coli*, marking the construction of the first recombinant DNA using restriction endonucleases as well as the beginning of the era of genetic engineering, also known as gene cloning. Now scientists could recombine DNAs at will and insert them into other organisms. In 1974, Boyer and Cohen, along with Chang, Helling, John Morrow, and Howard Goodman, succeeded in constructing a recombinant DNA molecule from the DNA of a plasmid and the ribosomal RNA-coding DNA of *Xenopus laevis*, the African clawed frog. After insertion of the recombinant plasmid/*Xenopus* DNA into *E. coli*, the recombinant DNA was transcribed into *Xenopus laevis* ribosomal ribonucleic acid (rRNA). This was the first demonstration of a eukaryotic DNA molecule (the rRNA gene from *Xenopus laevis*) being expressed in a foreign organism, *E. coli*. Boyer and Cohen next patented their gene-splicing technique.

In 1976, Boyer was promoted to professor of biochemistry and biophysics at UCSF, a position he would hold until his retirement in 1991. In Apri1, 1976, Boyer and Robert Swanson, a financier and venture capitalist who studied chemistry and management at the Massachusetts Institute of Technology (MIT), incorporated Genentech (Genetic Engineering Technology), a company whose first focus was to synthesize the human insulin gene, recombine it with a plasmid, and insert it into *E. coli* with the hope that the *E. coli* would synthesize human insulin. Swanson conceived of the project because the incidence of diabetes in the United States was increasing while the availability of bovine and porcine insulin was decreasing. Swanson and Boyer joined forces with Arthur Riggs, a geneticist at the City of Hope, a clinical research hospital in Duarte, California. By 1978, the Genentech/City of Hope team had successfully cloned and expressed the human insulin gene in *E. coli*. Genentech licensed the production and marketing of human insulin to Eli Lilly. Genentech, one of the leading biotechnology companies in the world, became a publicly traded company in 1980. In 1985, it became the first biotechnology company to produce and market its own medicinal product, human growth hormone (hGH), marketed under the name Protropin.

Boyer was vice president of Genentech until 1990, when he became a member of the board of directors. In 1994, he became a member of the board of directors of Allergan, Inc., a company that focuses on the discovery and development of innovative pharmaceuticals. He served as chairman from 1998 to 2001 and was elected vice chairman in 2001.

Boyer is the recipient of numerous awards, including the Albert Lasker Award for Basic Medical Research (1980), the National Medal of Science (1990), the Lemelson-MIT Prize for Invention and Innovation with Stanley Cohen (1996), the Albany Medical Prize (2004), and the Shaw Prize in Life Sciences and Medicine (2004). He was elected to the American Academy of Sciences in 1979 and to the National Academy of Sciences in 1985. In 1991, after a substantial gift by Boyer and his family, Yale University dedicated the Boyer Center for Molecular Medicine. In 2007, St. Vincent College renamed the School of Natural Science, Mathematics, and Computing the Herbert W. Boyer School. After retiring, Boyer became professor emeritus of biochemistry and biophysics at UCSF.

IMPACT

Boyer and Cohen's collaboration that led to the development of gene-splicing and genetic-engineering techniques had a profound impact on biology by revolutionizing the study of genetics and molecular biology. Their development of these techniques allowed for the construction, insertion, cloning, and expression of recombinant DNA molecules in foreign hosts and spawned the development of the biotechnology and biopharmaceutical industries.

Although the polymerase chain reaction (PCR) eventually replaced cloning as a method to amplify specific DNA molecules, the cloning of recombinant DNA molecules gave scientists a method to amplify and isolate specific DNA molecules to provide enough copies for DNA sequencing and analysis of gene structure and function. These analyses provided scientists with basic knowledge of the structure of the gene, the nature of mutations, and the control of gene expression.

The expression of recombinant DNA molecules in foreign hosts provided a mechanism for the production by foreign hosts of a variety of human proteins and enzymes to treat human disease. The first medicinally valuable protein that became commercially available was

PRODUCTION OF HUMAN INSULIN

Although Herbert Wayne Boyer, Stanley Norman Cohen, and their colleagues developed the basic techniques of gene splicing and genetic engineering, it was Boyer who orchestrated the development of these techniques into ones that could be exploited in the production of medicinally important proteins and enzymes, leading to the birth of the biotechnology and biopharmaceutical industries.

Financier Robert Swanson thought that the techniques could be used to produce human insulin, a protein that would be needed in the near future since the number of diabetics in the United States was increasing while the supply of bovine and porcine pancreases from which diabetics received their insulin was decreasing. Boyer and Swanson founded Genentech to produce human insulin. The Swanson-Boyer Genentech team elicited the assistance of Arthur Riggs and his colleagues at the City of Hope clinical research hospital in Duarte, California, in the project. Since the use of human DNA in recombinant DNA experimentation was not permitted by the National Institutes of Health guidelines involving recombinant DNA research, the Genentech-City of Hope team thought that the best approach was to synthesize the human insulin "gene" rather than to isolate it. Under a loophole in the guidelines, the use of a synthetic human gene in constructing recombinant DNA molecules would not be banned. The strategy was to synthesize, clone, and express in *Escherichia coli* (*E. coli*) bacteria cells a human gene that would code for human insulin. Riggs suggested that he and his colleagues Keiichi Itakura, Herb Heyneker, and John Shine first synthesize, clone, and express the human somatostatin gene since somatostatin was considerably smaller—fourteen amino acids compared to insulin's fifty-one amino acids. This project was completed in August, 1977, and published in December, 1977.

Soon after the somatostatin project was completed, the Genentech-City of Hope team, with the assistance of Itakura, David Goeddel, Dennis Kleid, and Roberto Crea, began the human insulin project. Since insulin is composed of two polypeptide chains, the strategy was to synthesize, clone, and express separately in *E. coli* a gene coding for each chain. The chains would then be isolated, mixed, joined, and folded into a functioning insulin molecule. On September 6, 1978, Genentech and City of Hope announced that they had successfully cloned and expressed the human insulin gene in *E. coli*. Twelve days earlier on August 25, Genentech licensed the production of human insulin to Eli Lilly. In 1980, a small-scale clinical trial involving fourteen patients was begun in England, followed by a much larger clinical trial in the United States in 1982. Human insulin became the first human protein of medicinal value to be produced by genetic-engineering techniques and approved for use by the U.S. Food and Drug Administration (FDA). The FDA approved the use of human insulin, marketed under the name Humulin, on October 29, 1982.

human insulin, in 1982. Insulin was quickly followed by the production of other recombinant human proteins, including hGH, interferon, tissue plasminogen activator (t-PA), and factor VIII clotting factor.

The Boyer-Cohen techniques also led to the development of a variety of transgenic strains of animals and plants. Today, animals such as goats, sheep, pigs, and cows are engineered to produce a variety of human proteins and enzymes of medicinal value, including t-PA, lactoferrin, factor VIII, factor IX, and alpha 1-antitrypsin. Plants are engineered to be insect-resistant, virus-resistant, and pesticide-resistant, allowing for increased yield and a reduction in the use of pesticides. Plants are also engineered to increase nutritional value. Rice, for example, has been engineered to produce beta-carotene, the precursor of vitamin A.

—*Charles L. Vigue*

Further Reading

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See also: Stanley Norman Cohen; Robert Charles Gallo; Mary-Claire King.

Otis Boykin

American electrical engineer

Boykin designed and produced electronic resistors and devices that were appropriated for various communication, military, and medical technologies. His inventions enabled faster and cheaper manufacturing of those basic electrical components that enhanced computer and other equipment performance.

Born: August 29, 1920; Dallas, Texas
Died: March, 1982; Chicago, Illinois
Also known as: Otis Frank Boykin (full name)
Primary field: Electronics and electrical engineering
Primary invention: Resistor

Early Life

Otis Frank Boykin was born on August 29, 1920, in Dallas, Texas, to Walter and Sarah Cox Boykin, both Texas natives. Walter identified his profession as a farmer in his World War I draft registration in September, 1918. At some point before the census of 1930, he became a Primitive Baptist minister.

Otis did not record details about his childhood or any educational, employment, or other experiences that might have shaped his inventiveness when he was a youth. According to census and primary records, he had four older brothers and a younger brother and sister. His family owned a house on Kynard Street in Dallas and had a radio that might have sparked Boykin's interest in electronics.

In 1938, Boykin completed high school and moved to Nashville, Tennessee, to begin studies at Fisk University, an African American college. He married Pearlie Mae Kimble on September 30, 1940. After meeting graduation requirements in three years, Boykin received an A.B. degree in 1941. He secured employment with the Majestic Radio and TV Corporation in Chicago and moved into a Maryland Avenue home. In that business's laboratory, Boykin evaluated automatic control systems used in airplanes and achieved promotions, eventually becoming foreman.

Scientific and industrial activity in Chicago and some local inventors and entrepreneurs probably encouraged Boykin's electronic endeavors. Sources do not indicate whether Boykin encountered any racial discrimination associated with his technological aspirations. He credited the Chicago Economic Development Corporation for providing African Americans, including himself, money to develop and market inventions. At some point,

THE RESISTOR

Otis Boykin improved the design of resistors, electronic components that restrict current in electrical appliances and machines. Concerned about costs and complicated procedures to produce resistors, Boykin sought to design resistors that could be made quickly and inexpensively in addition to minimizing their inductance and enhancing sealing and mounting processes. He considered his experiences with resistors in radios and other equipment at home, work, and school. He consulted patent records, technical journals, and electrical engineer Frederick Emmons Terman's *Radio Engineers' Handbook* (1943) to evaluate technical aspects of resistors.

With colleague Dr. Hal Fruth, Boykin devised his first resistor, and they received a patent for the device in 1953. Boykin constructed this resistor by shaping wire into a coil around an insulator, folding the sides toward the coil's center to lower inductance, and placing and sealing the coil in a tube-shaped structure. Boykin attached wire ends in the tube to terminals that emerged from the tube. Grooves on the tube aided the use of hardware to mount the resistor in appliances. The resistor could be set to specific resistance levels.

Boykin continued to improve his resistor design while working for the Chicago Telephone Supply Company (CTS). For his second patent, "Wire Type Precision Resistor" (number 2,891,227), issued in 1959, Boykin wrapped wire in several separate areas around a flat insulator, which he referred to as a tape, with each section's wires being wrapped in alternating directions. He folded the tape so that the wire sections touched. A plastic covering or similar material contained the folded tape.

For his third patent, "Electrical Resistor" (number 2,972,726), approved in 1961, Boykin addressed problems associated with resistor wires, wrapped around spools or bobbins, that stretched during reverse winding in production and how the size of those resistors hindered their use. He stated that his flat design, shaped to achieve maximum transfer of heat, did not involve reverse winding and had better terminals. His other resistor improvements incorporated glass, refractory materials, and metal oxides, as well as various mixing, shaping, and heating processes to strengthen resistor structures and conductivity.

Electronics inventors recognized the value of Boykin's resistors soon after his patents were approved. Patents that reference Boykin's various resistor patents include resistor designs using high resistance or thick films, such as the "Composite Film Resistors and Method of Making the Same" (number 6,480,093), issued in 2002. Boykin's wire-type precision resistor patent retained industrial significance, being referenced by inventor Kenneth M. Hays in his patent "Heating Elements with Reduced Stray Magnetic Field Emissions" (number 6,734,404), assigned to the Boeing Company in 2004.

Boykin joined such professional organizations as the American Association for the Advancement of Science (AAAS), the Physics Club of Chicago, and the International Society for Hybrid Microelectronics.

LIFE'S WORK

In 1944, Boykin accepted a position with P. J. Nilsen Research Labs in Oak Park, Illinois, performing engineering tasks. Sources do not indicate whether Boykin's work was associated with World War II programs or whether he served in any military capacity. He experimented with electrical materials to fashion unique devices and that year began designing a resistor, a device that limits the flow of an electrical current. Between 1947 and 1949, Boykin took classes at the Illinois Institute of Technology. He read technical books and periodicals on electronics and spoke with peers who had secured patents for various inventions.

Shortly after he left P. J. Nilsen Research Labs in 1949, Boykin established Boykin-Fruth, Inc., with physicist Dr. Hal Fruth and served as that corporation's president. Fruth, a telephone and radio electronics expert who had several patents, recognized Boykin's inventive potential. In addition to managing his business, Boykin earned income from other sources. The 1950 AAAS member directory listed his professional position as a research engineer for Lytle and Canon Engineering Laboratory.

On June 23, 1952, Boykin and Fruth filed with the U.S. Patent Office for a resistor with low inductive and reactive capacity that was inexpensive and easy to manufacture. In that year, they closed their company, and Boykin accepted a position at Radio Industries in Chicago, heading ceramics and plastics chemistry work. Boykin and Fruth were awarded a patent for the resistor on April 7, 1953 (U.S. Patent number 2,634,352). The following year, Boykin filed a patent for a wire-type precision resistor, which used precise currents for specific applications.

Boykin remained employed with Radio Industries through 1955. On February 27, 1956, he filed as the sole inventor for another electrical resistor, which had wires resilient to extreme temperatures and physical stresses, including acceleration and vibrations associated with rocketry, and which could be efficiently and economically manufactured. In 1957, Boykin began working for the Chicago Telephone Supply Company (CTS) in Elkhart, Indiana, as a senior project engineer. On June 16, 1959, the patent for his wire-type precision resistor (number 2,891,227) was assigned to CTS. His 1961 electrical resistor patent (number 2,972,726) was also assigned to his employer. During the early 1960's, Boykin applied for patents for his improved resistor designs, thin-film electrical capacitors, and electrical resistance capacitors. Some devices were designed in collaboration with CTS colleagues. Those patent rights were also assigned to CTS. After he retired from CTS in 1964, Boykin worked as an electronics consultant for businesses in the United States and Paris.

Boykin's inventions attracted the attention of the National Aeronautics and Space Administration (NASA). Aerospace engineers working in the Apollo program recognized the value of Boykin's resistors for essential control functions in spacecraft guidance systems. His devices were also used in guided missiles. Many sources incorrectly attribute the invention of the pacemaker to Boykin. Although he did not invent that cardiac device, his electrical components improved pacemaker technology.

In summer, 1975, Boykin sued CTS for $5 million in a New York district court, accusing the company of denying him profits generated by his resistor inventions. Boykin apparently had not received compensation beyond his salary, and he had been unable to sue before 1975 because of legal expenses. A letter from CTS claiming that Boykin had stolen materials from that corporation provoked him to pursue litigation. In October, 1977, Boykin filed a patent for a composite glass resistor he had designed with CTS colleagues and was awarded the patent (number 4,267,074) four years later.

On March 16, 1982, the *Chicago Tribune* printed a brief notice announcing Boykin's death but failed to indicate the exact death date or death place. Most sources state that Boykin suffered a heart attack and died in Chicago, but Cook County vital records do not have a death certificate for Boykin. Two of Boykin's patent applications for electrical resistors were approved posthumously, in 1983 and 1985.

IMPACT

Boykin made improvements to electrical components, particularly resistors, which have been used in a number of devices ranging from computers to pacemakers. One of Boykin's improved resistors could withstand extreme temperatures and shock, making it ideal for use in aerospace technology, particularly guided missiles. Concerned with manufacturing expenses, Boykin strove to design high-quality electronic components and efficient production methods, which appealed to manufacturers. As a result, Boykin's resistors were widely incorporated in domestic, business, and military electrical equipment. Starting in the 1960's, most radios and televisions and many appliances were built with Boykin's resistors.

Engineers relied on Boykin's resistors for use in computers—first in laboratories and government facilities, then in home computers starting in the 1980's. Though Boykin died before computer use became ubiquitous, his resistors greatly benefited the industry. One of Boykin's resistors was used in the pacemaker, a device that uses electrical pulses to regulate the heart rate, thus enhancing the health and life spans of millions of heart patients.

Although Boykin's inventions have played a fundamental role in advancing modern electronics technology, he received minimal recognition for his accomplishments. In Chicago, the Old Pros Unlimited Club presented Boykin its Cultural Science Achievement Award to recognize his inventiveness. Boykin never received national or international honors.

—*Elizabeth D. Schafer*

FURTHER READING

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Greatbatch, Wilson. *The Making of the Pacemaker: Celebrating a Lifesaving Invention*. Foreword by Seymour Furman. Amherst, N.Y.: Prometheus Books, 2000. Author describes his work related to pacemaker technology, referring to people who improved that device, but does not acknowledge Boykin's contributions to the technology. Explains technical details of pacemakers. Illustrations, glossary, endnotes, and appendixes.

Shnay, Jerry. "Chicagoan Aids Effort in Space." *Chicago Tribune*, October 27, 1968, p. NA3. Discusses Boykin's technological contributions to NASA and pacemaker advances. Provides quotations in which Boykin discusses financial support he received from Chicago African Americans for his work and patents. Notes local recognition of Boykin's achievements.

Taborn, Tyrone D. "Separating Race from Technology: Finding Tomorrow's IT Progress in the Past." In *Learning Race and Ethnicity: Youth and Digital Media*, edited by Anna Everett. Cambridge, Mass.: MIT Press, 2008. Historical analysis emphasizes that Boykin's electronics inventions were essential for the expansion of computer technology in the late twentieth century and aided the development of digitized processes.

See also: Wilson Greatbatch; Jack St. Clair Kilby; Gerald Pearson.

WILLARD S. BOYLE

Canadian physicist

In addition to the first continuously operating ruby laser, Boyle's principal contribution was the invention of the charge-coupled device (CCD) with George E. Smith. The device is ubiquitous in modern imaging hardware, including digital cameras, camcorders, and telescopes.

Born: August 19, 1924; Amherst, Nova Scotia, Canada
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Charge-coupled device; continuously operating ruby laser

EARLY LIFE

Willard S. Boyle was born in Amherst, Nova Scotia, Canada, in 1924 to Ernest Boyle and Bernice Dewar. When Willard was three years old, the family relocated to Chaudière in northern Quebec, where, because of the remote location, Boyle was home-schooled by his mother until the age of fourteen. He then moved to Montreal, where he attended Lower Canada College. Boyle excelled at school and was expected to progress to university; however, his matriculation was delayed when at the age of nineteen, during the latter stages of World War II, he joined the Fleet Air Arm of the Royal Canadian Navy. Although he became a qualified Spitfire pilot, he was not involved in serious confrontations, and the war ended soon after he enlisted.

After the war, Boyle returned to Montreal to pursue an academic career at McGill University, where he earned bachelor's and master's degrees in science (1947, 1948) and a Ph.D. (1950) in physics. After receiving his doctorate, he spent another year at McGill University as a postdoctoral researcher and then two years as an assistant professor teaching physics at the Royal Military College of Canada. In 1953, he moved to New Jersey to take a position at Bell Labs, where he began research into lasers and semiconducting materials.

LIFE'S WORK

While at the Royal Military College of Canada, Boyle collaborated with David C. Baird in an investigation of variations in the thermal and electrical conductivity of copper at liquid helium temperatures. These experiments necessitated the invention of an apparatus that allowed for the accurate regulation of temperature within a liquid helium bath, detailed in a 1954 publication. In 1953, while working for Bell Labs, Boyle continued his investigations into the electrical properties of materials, publishing work in 1955 and 1956 that showed the differing characteristics of short arcs generated between palladium and tungsten electrodes, the latter at high vacuum, dependent upon the voltage applied. Short-arc lamps are used today in a wide range of applications, including medical, military guidance, and fiber-optic illumination.

In the mid-1800's, a unique class of materials was identified whose ability to conduct electricity could be varied depending on the given conditions; these materials were dubbed "semiconductors." The importance of electricity and what was to become the electronic industry grew over the following decades, significantly with the advent of electrical lighting and radio communications. The latter was only possible through the invention of a semiconductor device known as a rectifying diode, which allowed electrical current to flow in only one direction through the radio transmitter. At Bell Laboratories, Russell Ohl had discovered that semiconductors could be "doped" with other elements to tailor their properties even further. This led to the invention of the silicon-based solar cell in 1941 and laid the groundwork for further exciting developments at Bell Labs.

The field of semiconductors continued to see significant advances in the later part of the twentieth century, including contributions from Boyle. Boyle's early studies on semiconductors at Bell Labs focused on their interaction with infrared radiation. His investigations dealt with the quantum mechanical aspects of the materials—

that is, the discrete energy levels allowed for the individual particles therein. In 1958, he published the first measurements of the energy levels of particles in cyclotrons, as deduced from infrared spectroscopic studies. Many of his studies involved the element bismuth, and in 1963 he published a comprehensive review of the properties of the element with other members of Bell Labs, including George E. Smith, with whom he was to have other fruitful collaborations.

In 1960, Theodore Harold Maiman shone an intense pulsing lamp onto a sample of ruby coated in silver and found that an intense beam of coherent visible light was emitted in pulses from the ruby; he called the device a laser. The intense lamp used in the experiment excited atoms in the ruby sample, causing it to emit light of a very specific wavelength. Excitation of the sample is known as "pumping" the laser, and a number of methods and devices exist for doing this. In the months following Maiman's report, a similar laser using a mixture of helium and neon gases instead of ruby was reported by Ali Javan, William Bennett, and Donald Herriott at Bell Labs. The light was continuously emitted rather than appearing in pulses as in Maiman's machine. These happenings significantly influenced the work of Boyle, who in collaboration with Donald Nelson developed the first continuously pumped ruby laser at Bell Labs in 1962. Their invention relied on an arc lamp (of which Boyle had experience from his 1956 studies) that shone continuously rather than the flash lamp used by Maiman. In 1962, Boyle (with David Thomas) filed for the first patent proposing a semiconductor injection laser. Lasers produced with a semiconducting material are significantly easier to fabricate than those that use more traditional materials such as ruby or gases. As a result, they are used in numerous everyday applications such as bar-code scanners, compact disc players, and laser pointers.

In 1962, Boyle worked briefly for Bellcomm, a subsidiary of Bell Labs, as the director of Space Science and Exploratory Studies; however, he returned to Bell Labs in 1964 as executive director of Device Development to continue his study of the physics and application of semiconductors. This appointment led to his invention in 1969 of the charge-coupled device (CCD) with George E. Smith. Concurrently, a separate group at Bell Labs

THE CHARGE-COUPLED DEVICE

Willard S. Boyle and George E. Smith originally envisioned the charge-coupled device (CCD) to be used for memory storage. The device in its simplest form can be seen as a row of discrete capacitor units made from semiconducting materials. As the name suggests, capacitors are vessels capable of storing electrical charge, and so either the presence or lack of charge in a series of units can be interpreted as a series of ones and zeros, hence the possibility of a binary memory system. By carefully applying a varying voltage to a row of capacitor units in a CCD, stored electrical charge can be passed along from each unit to its neighbor, rather like a line of people holding buckets, the contents of which are poured from one bucket to the next in line. The content of each bucket (the charge) is assessed when it reaches the end of the line, where it can be recorded as a series of ones and zeros. The name "charge-coupled device" comes from the fact that neighboring capacitor units are in effect coupled, and electrical charge is transferred between them.

The area in which the CCD has had the biggest impact is undoubtedly the electronic-imaging industry. A simple imaging CCD is a row of capacitors covered with a photosensitive layer of silicon. When the device is exposed to light (an image, usually through a focusing lens), the charge accumulated in each of the capacitors is proportional to the energy of the light rays incident upon the silicon. When the packets of charge are passed along the CCD and read off, the differing amounts can be reconstructed into an image. This type of one-dimensional CCD is used in fax machines to scan documents; successive 1-D images of the document are taken as it moves through the machine, and these are combined to give an overall picture in digital format. Rather than taking individual strip images, a two-dimensional CCD array can be constructed to provide an instant 2-D image, as used in modern digital cameras, camcorders, and cell phones.

The digital information gathered by CCDs can be easily manipulated with modern computers. Another great benefit of the CCD imaging system is that the device is solid state and is therefore both robust and easily fabricated. Today, CCDs can be manufactured with several billion capacitor units packed into a tiny area. Each tiny unit has the ability to detect individual photons incident upon it, making these devices incredibly sensitive. Since the 1980's, astronomers have been harnessing this sensitivity, building telescopes that can study extraplanetary objects far fainter than previously imagined and mapping the surface of Earth with exceptional detail using satellite imaging. The famous Hubble Space Telescope uses a number of highly specialized CCDs to produce stunning X-ray, ultraviolet, infrared, and visible-wavelength images of the cosmos. These pictures have helped to further our basic understanding of the universe.

was investigating the manipulation of bubbles of magnetism on the surface of metals. Boyle and Smith extended these ideas to packets of charge that could theoretically be manipulated on a semiconductor surface. The initial brainstorming session took less than an hour, and the working model of a charge-coupled device was assembled in the following few weeks. The CCD was originally conceived for the purpose of memory storage; however, its potential as an imaging device was realized soon after its invention. By 1975, a CCD had been incorporated into a television camera.

Boyle was named director of research in Bell Labs' Communications Sciences Division in 1975 and remained active in research until his retirement in 1979. He has received a number of awards in recognition of his role in the invention of the CCD and is a member of many professional organizations. He and his family reside in Nova Scotia.

IMPACT

Boyle worked at Bell Labs during a very exciting period of discovery in the fields of laser and semiconductor research. He was responsible for fundamental innovations in both fields that have become commonplace in modern-day technology. Part of this success is due to the collaborative nature of research at Bell Labs and its supportive environment.

Boyle's contributions to laser technology came at a time just after the first laser device had been fabricated. Following his invention of the continuously pumped ruby laser, devices using this technology were used extensively until the late twentieth century, when more efficient lasing materials were discovered. Semiconductor lasers are used in a wide range of applications today, and Boyle is credited with expanding this field.

Boyle will be best remembered for his coinvention of the charge-coupled device, which was first fully described as a memory device in the *Bell Systems Technical Journal* in 1970. However, its most important applications have been in imaging technologies. The imaging CCD is an array of many millions of light-sensitive semiconductor-based units. When the array is illuminated, as when a photograph is taken, an image can be built up based on the interactions of each semiconductor unit with different quantities of incident light. The sensitivity of the CCD, and hence the sharpness of the image, is restricted only by the number of semiconductor units. Fabrication of CCDs is relatively easy, and since they are solid-state devices, they are both durable and practical. CCDs have become ubiquitous in all modern digital cameras, camcorders, and even powerful telescopes. Moreover, their use is not restricted to visible light: Modern innovations have led to devices that interact with X-ray, ultraviolet, and infrared radiation. CCDs were used to map the background microwave radiation left over from the big bang event.

—*Bruce E. Hodson*

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Shell, Barry. *Sensational Scientists: The Journeys and Discoveries of Twenty-four Men and Women of Science*. Vancouver: Raincoast Books, 2005. One chapter of this book deals with Willard S. Boyle. Includes a brief résumé with a portrait photograph, in addition to anecdotes about the events surrounding the invention of the charge-coupled device. Boyle's early life is discussed in a separate section. Quotes from and photographs of the inventor in later life are included, as well as a pictorial explanation of a CCD unit.

See also: Ali Javan; Theodore Harold Maiman.

LOUIS BRAILLE

French teacher

As a blind teenager, Braille invented the Braille code, a system of raised dots that allows blind people to read with their fingers and to write using special tools.

Born: January 4, 1809; Coupvray, France
Died: January 6, 1852; Paris, France
Primary field: Communications
Primary invention: Braille system

EARLY LIFE

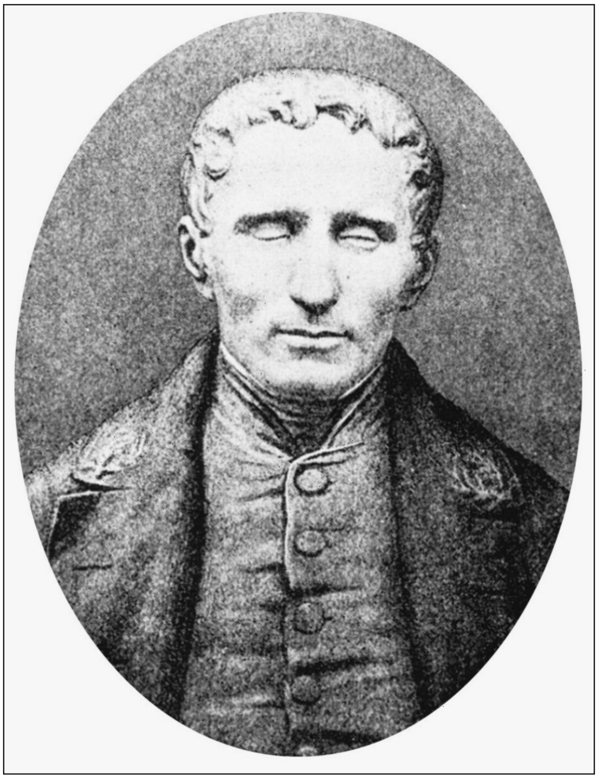
Louis Braille (LEW-ee brayl) was the youngest child of Simon-René Braille, a harness and saddle maker, and Monique Braille. Braille's parents were literate—a fact worth noting since in the countryside east of Paris this was unusual for people of their social class, even relatively prosperous people like the Brailles. A bright and attractive child, Louis was adored by his brother and two sisters and his parents. As a toddler, he spent time in his father's workshop, watching Simon-René work while playing with his tools and supplies.

In 1812, three-year-old Louis accidentally blinded himself with one of the tools. In spite of this disability, when he reached the appropriate age his parents prevailed upon the parish priest to help enroll him in school. The local teacher quickly took note of Braille's intelligence and ability to memorize readily what the other pupils were able to write down. Braille was understood to be one of the brightest boys in the school, and his parents, priest, and teacher all determined to find a means to continue his education beyond what was available in their regional market town.

Braille's childhood in Coupvray was marked by the defeat of the Emperor Napoleon's army and subsequent occupation of the town by enemy soldiers. The difficult circumstances brought on by the occupation increased his parents' concern about how their blind son would support himself in later life. For this reason, on February 15, 1819, Braille's father took him to Paris to be admitted as a residential student at the Royal Institute for Blind Youth. The first modern school for the blind, the institute had been established three decades earlier by Valentin Haüy, a sighted person dismayed by the poor treatment accorded blind people. Haüy was determined to provide the blind with skills to support themselves by work rather than charity and saw literacy as central to his goal. He devised a system for embossing raised letters on heavy paper. These formed words that his blind students could feel, recognize, and therefore read. Haüy's educational program included training in both trades considered suitable for the blind and academic studies such as mathematics, geography, and Latin. He also encouraged talented students to pursue musical performance.

LIFE'S WORK

This was a time of rapid change in France, and Haüy's approach fared poorly during the revolutionary and Napoleonic eras. From 1801 until 1815, his school was housed in a charity institution for blind adults, and between 1806 and 1817 Haüy himself lived in exile in Russia. When the school finally moved back into its own quarters, the students found that they were living in a wretched building, several centuries old, dank, and with classrooms created by dividing up corridors. The new director, Sebastian Guillié, successfully revived Haüy's system of embossed books, but his poor treatment of the students only exacerbated the effects of the unsuitable building on their health. Upon his dismissal (for an affair



Louis Braille. (Library of Congress)

THE BRAILLE CODE

Louis Braille created the first truly practical system of tactile symbols that allowed the blind, using their fingers, to read with the comprehension and speed of sighted people reading print. He built on the efforts of two sighted people: Valentin Haüy, a philanthropist and educator who produced books with embossed letters of the alphabet for his blind students, and Charles Barbier, a military officer who devised a code of raised dots for transmitting messages and orders in the dark. Barbier's code used thirty-six phonetic symbols, each represented by a "cell" of two columns containing between one and six dots. The Braille code was unlike Haüy's embossed letters (which were the same shape as the printed alphabet) or Barbier's dots (which were phonetic). Using the sixty-three possible combinations of between one and six dots in a cell of two columns and three rows, the Braille code has a one-to-one correspondence with the letters of the alphabet and punctuation marks. The smaller cell size was readily read by touch, and one-to-one correspondence with letters of the alphabet allowed for easier written communication between blind and sighted people. Braille's system became dominant in France shortly after his death and subsequently spread throughout the world.

with a female teacher), Guillié was exposed as having lied about the students' nutritional status. Many were underweight and some—including Braille—were eventually to fall ill with tuberculosis.

In any case, Braille adapted quickly to his new home. His kind nature and native intelligence brought him friends among the students and recognition by the teachers and administrators. He learned to read using Haüy's embossed letters and regularly won prizes as the best student in one or another subject. Braille could tell, though, that many blind students had difficulty recognizing raised alphabet letters, and few learned, as he did, how to write with pen and ink. Even particularly adept students could not develop much speed reading embossed letters.

Braille's inventive genius was set in motion by an 1820 visit to the institute by Charles Barbier, a retired artillery officer who had devised a military code that used raised dots. Since the code could be read by touch, messages and orders could be decoded at night without a light that might reveal one's position to the enemy. Disappointed in his attempts to get the army to adopt his system, Barbier realized that it could be used by the blind. He demonstrated its use to Guillié, who agreed to test the code with his blind students. Braille was thus introduced to the idea of the blind reading with raised dots. He recognized the superiority of such a system over embossed letters, and he set out to produce a more accessible code than Barbier's.

Braille invented the Braille code while a teenager, working at it during both his free time at school and his summer vacations at home. By the time he published the code in a pamphlet in 1829, Braille had taught it to many of his fellow students, who confirmed that it enabled them to communicate in writing as no other system could. Meanwhile, in 1821, Alexandre Pignier replaced Guillié as director. Pignier paid attention to his students' interest in the Braille code and, although regulations prevented him from making it part of the formal curriculum, he allowed his students to study it on their own. He took particular interest in Louis Braille, and, upon the death of Braille's father in 1831, he promised that he would never abandon the blind young man.

As it turned out, Pignier was himself dismissed in 1842, the victim of intrigues by his assistant, Pierre Dufau. As director, Dufau tried to suppress the use of Braille's code and force on students his own modifications of the Haüy system. However, Dufau's assistant, Joseph Gaudet, noticing how well the students read and wrote using Braille, chose to publicly announce his support for the dots at the opening ceremonies for the institute's new building (where it remains in 2008, as the National Institute for Blind Youth). Publication of Gaudet's speech in pamphlet form provided the impetus the Braille code needed to lead, in 1854, to its adoption as the authorized system in France. Unfortunately, this was two years after Louis Braille had died.

During his twenties and thirties, Braille remained at the institute as a teacher, supplementing his income with a job as a church organist. A talented musician, his 1829 publication included a code for musical notation as well as the written alphabet. During the years that students at the institute informally (and sometimes surreptitiously) made use of his code, Braille continued to improve his system for music. He also undertook to invent a method for writing letters of the Roman alphabet using dots. Though this method was slower than writing the Braille code, Braille saw his raised-dot system as providing blind people the ability to communicate on paper with sighted people. In 1844, he met another talented blind inventor, Pierre-François-Victor Foucault, with whom he collaborated on a mechanical device, a predecessor to the typewriter, that produced raised-dot letters of the alphabet.

By the time the institute moved into its new home—a modern, salubrious building—Braille's tuberculosis had progressed to the point where it was incurable by the means available at the time. No longer able to maintain his regular schedule as a teacher, Braille spent several extended periods at home in Coupvray. While in Paris, he limited his work as an organist and reduced his teaching load. His condition became acute shortly before Christmas of 1851, and he succumbed a few weeks later, two days after his forty-third birthday.

IMPACT

Although Valentin Haüy was not the first to create a system for the blind to read by touch, no earlier attempt had ever been institutionalized. Braille's exposure to Haüy's method, and then Barbier's code, led him to create the first truly workable system for blind literacy. Readily understood by the blind and easily adaptable from French to other European languages, Braille was being used in the instruction of blind children in many western European countries by the end of the nineteenth century. The Braille code had a number of competitors (most based on principles derived from Braille) in the United States, and only in 1917 did it become the standard. In 1949, the government of India encouraged the United Nations Educational, Scientific, and Cultural Organization (UNESCO) to regulate Braille for use in all languages, regardless of writing system.

Until the development of sound recording and the subsequent adoption of discs and tapes for distribution to the blind by libraries, Braille and similar codes provided the only access to reading material for the blind. Braille literacy reached a peak in the middle of the twentieth century. More recently, sound recordings and specialized computer programs have led to a decline in Braille usage and the claims by some that Braille code is obsolescent. Among the organized blind, though, there remains great support for teaching Braille to visually impaired children beginning at the same age as the sighted learn to read print. In 2009, to mark the bicentennial of Louis Braille's birth, the U.S. Mint issued a commemorative one-dollar coin.

—Edward T. Morman

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Bickel, Lennard. *Triumph over Darkness: The Life of Louis Braille*. Leicester, England: Ulverscroft, 1988. A competent and accurate account of Braille's life and influence. It tends toward the hagiographic and in florid language perhaps overemphasizes the devotion of the Braille family and Alexandre Pignier to the deposed French royal family and the Catholic Church.

Dixon, Judith, ed. *Braille into the Next Millennium*. Washington, D.C.: National Library Service for the Blind and Physically Handicapped, 2000. A collection of articles on the history and current status of tactile reading systems for the blind. Published in print and Braille.

Irwin, Robert B. "The War of the Dots." In *As I Saw It*. New York: American Foundation for the Blind, 1955. A firsthand account of how the Braille code eventually became the standard in the United States.

Mellor, C. Michael. *Louis Braille: A Touch of Genius*. Boston: National Braille Press, 2006. The print edition contains numerous beautiful illustrations that are described in detail in the Braille edition. The illustrations of the Braille and Barbier codes and of Foucault's invention clarify for the reader how they work. Although catalogued as a children's book by the U.S. Library of Congress, this is in fact a well-documented book based on primary materials, many of which are reproduced within it.

Roblin, Jean. *The Reading Fingers: Life of Louis Braille, 1809-1852*. Translated by Ruth G. Mandalian. New York: American Foundation for the Blind, 1955. This was originally published in French to commemorate the one hundredth anniversary of Braille's death. Accurate but occasionally hard to follow, this short work provides the English-speaking reader a sense of how Louis Braille has been viewed in France.

See also: Patricia Bath; Alexander Graham Bell.

GIOVANNI BRANCA

Italian engineer and architect

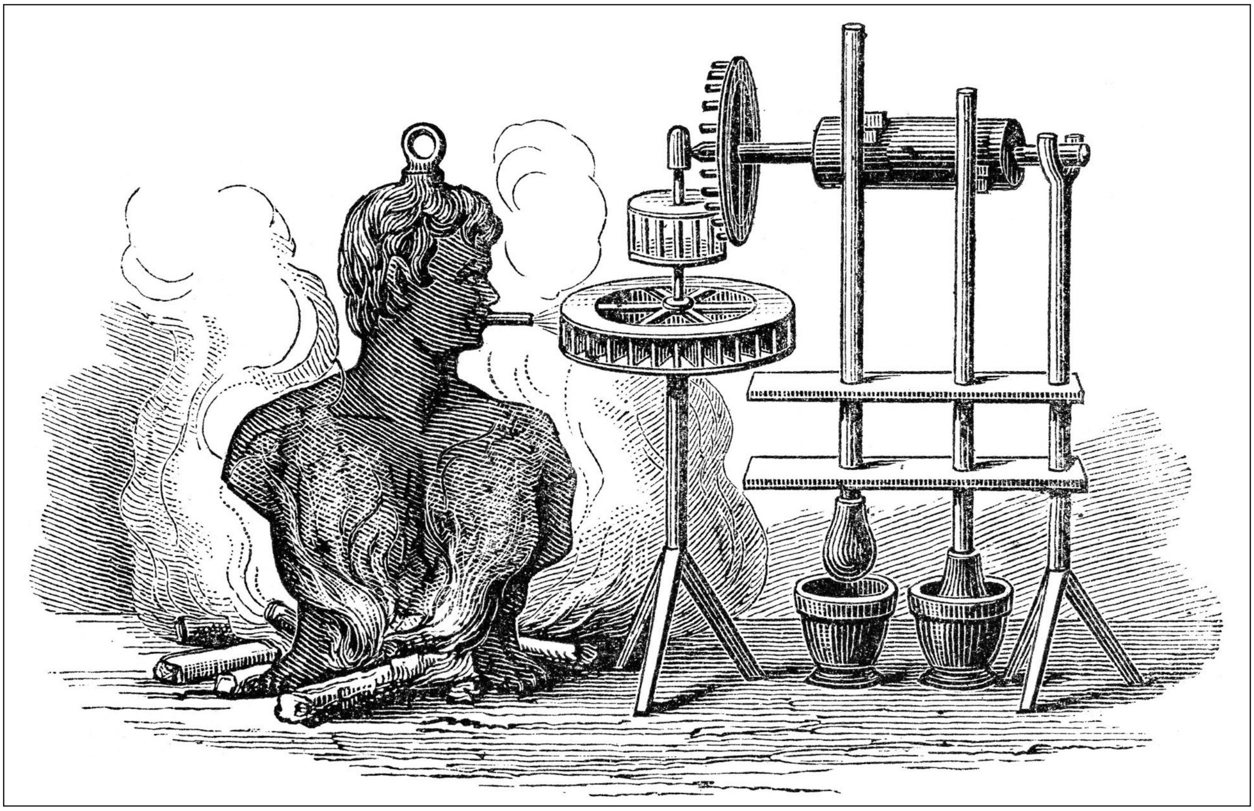
Branca's modern fame rests on his illustration of a steam machine in Le machine *(1629). In his own time, Branca was an accomplished architect, engineer, and writer; his two books, both published in 1629, attest to his ability to compile and present technical information to nonprofessional audiences.*

Born: April 22, 1571 (baptized); Sant'Angelo in Lizzola, Pesaro (now in Italy)
Died: January 24, 1645; Loreto (now in Italy)
Primary fields: Architecture; civil engineering
Primary invention: Steam turbine

EARLY LIFE

Giovanni Branca (joh-VAHN-nee BRAHN-kah) was born in Sant'Angelo in Lizzola, a small town in Pesaro (in the region of the Marches), in 1571. As an archival document attests, he was baptized there on April 22, 1571; his father was an otherwise undistinguished "maestro Niccolò." Nothing else is known about Branca's early life. Because Branca dedicated his *Manuale di architettura* (1629; manual of architecture) to Count Cesare Mamiani, who owned the fief adjoined to the castle of Sant'Angelo, some biographers have speculated that this nobleman supported the early education of Branca in Rome, the city to which he was connected throughout his adult life.

In Rome, Branca would have received his elementary education and the rudiments of the mechanical arts, which, in this period, involved the study of classic texts on architecture and mechanics, such as those by Vitruvius, Leon Battista Alberti, and Aristotle. However, the language as well as the technical aspects of his texts do not support the hypothesis that Branca received any advanced schooling or university training. Against this persistent historiographic supposition, it should be noted that the Marches benefited from a strong tradition of mathematical and engineering studies during the six-



Giovanni Branca's steam engine, as described in his work Le machine *(1629).* (The Granger Collection, New York) teenth century, epitomized by the fact that the court of Urbino was home to Federico Commandino and Guidobaldo del Monte.

Life's Work

After his baptismal certificate, the next surviving document on Branca mentions his 1614 appointment as "architect to the House of Loreto," a position he kept for the rest of his life. One of his first projects in this papal town outside of Rome, which was also an important pilgrimage site, concerned its aqueduct. Specifically, he was charged with correcting the engineering mistakes made to it by none other than Giovanni Fontana and Carlo Maderno, two leading architects of the Roman scene. In 1614, Branca was also granted Roman citizenship; rather than an honorific recognition, this title offered fiscal and legal advantages. In Loreto, in addition to supervising the building of the town's main church, Branca oversaw the maintenance and enlargement of the town's walls, including the addition of two pentagonal bastions to increase Loreto's defenses.

The Wonderful Motor

Figure 25 in the first section of Giovanni Branca's *Le machine* (1629) is the illustration that made him famous in modern times. Many historians have seen in this machine an anticipation of the steam-powered machines that were developed during the eighteenth century. This assessment is more correct with respect to the steam turbine, which is primarily a twentieth century technology, than in relation to James Watt's steam piston machine. Branca's figure presents a boiler, a kind of pressure cooker, in which a set amount of water is turned into steam by the heat provided by coals burning underneath. The steam jet coming out of the mouth of the human-head-shaped lid is channeled through a pipe. The steam jet exiting from this pipe thrusts the blades attached to a drive shaft, producing rotary motion that is transmitted through a mechanism comprising three sets of gears. In the end, the rotary motion of the drive shaft produces the power to activate two pestles. After following the process of the machine's workings through the stations clearly labeled by letters in figure 25, the terse commentary explains that this *motore meraviglioso* (wonderful motor) is used to crush the ingredients necessary to produce gunpowder.

It should be noted that from the perspective of the history of technology, Branca's invention is indebted to the researches on the application of steam power pursued by Renaissance engineers, including Leonardo da Vinci. In their writings, they considered steam power, probably because Vitruvius referenced it in his *De architectura* (c. 20 B.C.E.; *On Architecture*, 1711), a text that circulated widely in the early modern period thanks to various editions and translations. Considering the design of the figure and the proposed machine from the standpoint of subsequent developments, Branca's machine emerges as a precursor not of the eighteenth century steam engines, which worked through a cycle and were usually based on pistons, but of the twentieth century steam turbines that, like his, harnessed directly the power of the steam.

In 1629, Branca published in Ascoli (a large town in the Marches) his *Manuale di architettura*, an introductory manual of architecture for aspiring architects and builders. In the first three books of this manual, Branca covers building materials, the classical orders, and general instructions to design and build windows, vaults, stairs, chimneys, and other architectural elements. In the remaining three books, he explains the basic mathematical rules and principles needed by architects. The volume concludes with a series of thirty precepts and rules applicable to the problems of maintaining and changing the course of rivers, a subject on which Branca can claim primacy. Notably, unlike his other publication, this manual enjoyed considerable success, seeing several editions until 1789.

Published in Rome in 1629, *Le machine* presents seventy-seven figures and is divided into three sections, the first covering machines of diverse kinds; the second, pumps and hydraulic mechanisms; the third, siphons and compressed-air devices. On the page facing each illustration, there is a brief discussion (in both Italian and Latin) of the machine pictured, including its identification and application. As Branca states in the foreword, he does not claim to have invented many of the devices discussed. Generally speaking, *Le machine* belongs to the literary genre of the "teatri di macchine" (theaters of machines) that emerged during the second half of the sixteenth century. These were not engineering treatises but "coffee-table books" featuring illustrations of machines. Rather than explicating physical and mechanical principles, these books aimed at entertaining readers, as confirmed by the fact that their text and commentaries are often written in Latin, which at the time was not the language of practicing engineers but of the intelligentsia.

Within this genre, Branca's book distinguishes itself by the following features: It was the first non-luxury publication, it was a small octavo, and its figures are unsophisticated woodcuts. Evidently, Branca understood that this kind of publication had a wider market. Even though the steam machine, the invention for which this book and its author became most famous, is defined as a "wonderful engine"—a qualification partly hinting at the fact that it may not be a real machine—in other instances Branca illustrates models that certainly work in actuality, such as the water pump, a device to raise water. His ingenuity in employing raised water to perform work is demonstrated in figure 20. The Archimedean screw was a device commonly used to raise water; Branca "inverted" its principle: Water runs down the Archimedean screw cylinder, which, by turning, generates the power needed to operate a spinning wheel. Branca presents two applications of steam power. In addition to the steam machine, he envisioned a "smoke turbine": A wheel is powered by the fumes and hot air produced by a furnace and channeled through a long funnel-like chimney; a series of gears then transmits the motion to the cylinders of a rolling mill that can be used to strike medals or to thin metal bars.

Documents from the 1620's and 1630's reveal that Branca was granted lands as well as other public offices to administer the realty in Loreto, while also serving as judge and, eventually, "mayor" from July of 1644. He died on January 24, 1645, at the age of seventy-four.

IMPACT

Branca is representative of the Renaissance engineer-authors and inventors. His publication on machines epitomizes early modern engineering knowledge, both real and fanciful. Branca's steam turbine, for which he is famous, is not a practical device. It is based on working principles, but its realization and applicability was impossible because of the extremely precise and durable gears necessary to harness steam power at the pressure and speeds he envisioned. The machine is significant for continuing the intellectual thread that began with Hero of Alexandria (first century C.E.)—inventor of the aeolipile, the first steam engine—and that can be connected to the creation of modern steam machines. Because few of Branca's illustrations could be or were ever translated into three-dimensional working machines, the impact of his inventions was limited, serving above all as food for thought to stimulate thinking and research about these scientific principles and engineering solutions. In this respect, it is significant that two famous contemporaries owned copies of his machines book—the English natural philosopher Robert Hooke and the Italian architect and artist Gian Lorenzo Bernini.

—*Renzo Baldasso*

FURTHER READING

Keller, Alex. "Renaissance Theaters of Machines." *Technology and Culture* 19 (1978): 495-508. Tackles important intellectual issues concerning the history of the "theaters of machines" while also reviewing misconceptions about this genre that are frequently found in the older historiography on the history of technology.

_______. *A Theatre of Machines*. London: Chapman & Hall, 1964. In addition to an informative introduction and biographical accounts of Renaissance engineer-authors, this book presents a sample of illustrations from the "theaters of machines," including figures from Branca's work. The commentary is also illuminating.

Lefèvre, Wolfang, ed. *Picturing Machines, 1400-1700*. Cambridge, Mass.: MIT Press, 2004. Important collection of essays that examines the role of images and visual representation within the intellectual and cultural dimensions of the history of early modern science and technology. Useful for placing Branca's work within the scientific and technical context of the seventeenth century.

McPhee, Sarah. "Bernini's Books." *The Burlington Magazine* 142, no. 1168 (2000): 442-448. Describes and comments on the inventory of the library owned by the architect and artist Gian Lorenzo Bernini. The fact that Branca's *Le machine* is one of these 169 volumes is significant because it is testimony to the position of Branca's work within the intellectual environment of the mid-seventeenth century.

Thorndike, Lynn. *A History of Magic and Experimental Science*. Vol. 7. New York: Columbia University Press, 1958. Thorndike's two pages (617-618) on Branca's book demonstrate above all the difficulty modern historians have in dealing with his work, the technical dimensions of which are easily misunderstood and dismissed as daydreaming, while completely missing the importance of the popular dimension of machines design and of the "theaters of machines" as a literary genre.

See also: Archimedes; Ctesibius of Alexandria; Galileo; Hero of Alexandria; Robert Hooke; Al-Jazarī; Leonardo da Vinci; Thomas Newcomen; Charles Parsons; James Watt; George Westinghouse.

JACQUES EDWIN BRANDENBERGER

Swiss French chemist and textile engineer

Brandenberger's goal of producing a stain-resistant cloth in the early 1900's was unsuccessful, but his experiments resulted in the invention of cellophane. Cellophane plays a large role in food preservation and safety, medicine, and other industries.

Born: October 19, 1872; Zurich, Switzerland
Died: July 13, 1954; Zurich, Switzerland
Primary fields: Chemistry; household products; packaging
Primary invention: Cellophane

EARLY LIFE

Little is known about Jacques Edwin Brandenberger's early life. He was born on October 19, 1872, in Zurich, Switzerland, and attended the University of Bern, where he majored in chemistry. In 1895, he graduated summa cum laude with a doctorate in chemistry. At age twenty-two, he was the youngest Ph.D. in Switzerland. After graduation, he moved to France, where he worked for a textile firm.

LIFE'S WORK

Around the turn of the century, Brandenberger was having dinner in a restaurant where someone at a nearby table had spilled a glass of red wine. While watching the wine stain spread, Brandenberger thought to design a waterproof cloth material. He based his work on that of English chemists Clayton Beadle, Charles Cross, and Edward Bevan, who in 1882 discovered that cellulose could be converted into soluble sodium cellulose known as xanthogenate by using sodium hydroxide and carbon disulfide. They then immersed the resultant material in an acid bath that converted it back to cellulose. Brandenberger initially experimented with rayon, a type of cellulose, in liquid form. However, the rayon made the cloth too stiff to work with and did not stick to it. Brandenberger's idea for waterproof cloth failed, but he noticed that the thin, transparent viscose film could be peeled off the cloth. He washed and bleached the film, and by 1908 he had successfully built a machine capable of mass-producing the product.

Brandenberger named his new product "cellophane," from the words "cellulose" and *diaphane*, the French word for "transparent." He published an article in the French magazine *Illustration* in which he discussed the multifarious uses for the new material. In 1913, Brandenberger founded La Cellophane, setting up its headquarters in Paris. The cellophane manufacturing plant was built in the nearby town of Bezons. During World War I, his company produced a large amount of cellophane that was used in the protective eye shields for gas masks. In 1911, Brandenberger patented his production methods and machines. Whitman's was the first American company to use cellophane. Starting in 1912, the candy company began wrapping its Whitman's Sampler

CELLOPHANE

Cellophane, a staple of most modern-day kitchens, was invented by accident in 1908. The idea for waterproof cloth came to Jacques Edwin Brandenberger after he observed a wine stain on a restaurant tablecloth. Though he succeeded in producing a thin, clear film, he could not get it to stick to cloth. He eventually abandoned the waterproof cloth idea and focused on experimenting with the thin viscose sheet. After a decade of experimenting, Brandenberger successfully built a machine capable of mass-producing his cellulose sheets. He patented the production methods and machines in 1917.

Cellophane is made from wood, cotton, hemp, and other natural elements containing cellulose fibers. The cellulose material is dissolved in a solution of carbon disulfide and alkali. The resulting mixture is a liquid known as viscose. To convert the viscose back into cellulose, the solution is sent through a slit into an acid bath. Cellulose, and therefore cellophane, is made up of carbon, hydrogen, and oxygen.

In 1923, DuPont was sold the rights to manufacture and sell cellophane in North and Central America. DuPont scientist William Hale Charch and other researchers developed a process for making waterproof cellophane. Charch conducted more than two thousand experiments before finding the right mixture in 1927. Thus, DuPont began producing a wide line of regular and waterproof cellophanes—with different colors, thicknesses, and textures. DuPont also found ways to make cellophane production more cost-effective. Its scientists adapted machines to cut and fold the thin material. The chemical company also developed the adhesives to seal cellophane. With DuPont's aggressive marketing, cellophane became the common packaging for bread, cakes, cookies, and meats. The company sold cellophane as packaging for nonfood items such as toiletries and tobacco, and it established a department to come up with new uses for cellophane, such as holiday gift basket wrapping.

in the plastic. The new packaging kept out bugs and allowed the candy to be shipped nationwide for the first time.

Brandenberger was known for testing new or potential employees by giving them seemingly unsolvable tasks. Around 1921, he hired a young man on a probationary status. The employee was asked to turn a paper-bag-folding machine into one that would be able to make cellophane bags. Cellophane bags had to be made by hand, requiring a large workforce; Brandenberger envisioned a more effective method of production. After six weeks, the employee came to the conclusion that it was impossible to use the paper-bag-folding machine to make cellophane bags. He feared that he would be fired when he told Brandenberger this. Instead, Brandenberger commended him for having the courage to be honest and for being a hard worker, and the man kept his job.

Whitman's was the largest importer of cellophane until 1924. In 1923, La Cellophane licensed the U.S. rights to cellophane to the DuPont Cellophane Company, and the Delaware chemical company built its factory the following year. DuPont was given exclusive rights to La Cellophane's manufacturing processes and sales rights for North and Central America. In return, La Cellophane would hold the cellophane patent rights and sales rights for the rest of the world.

On December 13, 1947, the U.S. government filed a civil suit against DuPont, accusing the company of monopolizing interstate commerce of cellophane. It took six years for the district court of Delaware to make a ruling. Chief Judge Paul Leahy wrote the decision stating that DuPont did not violate the Sherman Antitrust Act. After reviewing the evidence—hours of testimony and more than seven thousand documents—Leahy felt that DuPont was acting as a competitor, not a monopoly: DuPont conducted market research, consumer surveys, developed new and better products (offering more than fifty types of cellophane), and looked for ways to cut costs.

In 1937, Brandenberger was awarded the Elliot Cresson Medal by the Franklin Institute of Philadelphia. Unlike some inventors, he was able to see how popular his invention became and the impact it had on the world. Besides its use in food packaging, cellophane is used in Scotch tape, some batteries, and Visking tubing for dialysis. Cellophane is also part of the manufacturing processes of fiberglass and some rubber products.

Brandenberger was able to retire comfortably and enjoyed collecting French antiques. He died on July 13, 1954, at the age of eighty-one. He had one daughter, Irma Marthe Brandenberger, who established a foundation in her father's name to honor people who have contributed to the welfare of humankind.

IMPACT

Cellophane is one of the most common packaging materials in the world. Fresh flowers, holiday gift baskets, packs of chewing gum, boxes of tea, and various types of candy are just a few examples of products that come wrapped in cellophane. Brandenberger's accidental discovery of cellophane revolutionized food storage and safety. Cellophane-wrapped meats and produce lasted longer and kept out bugs. The product also led to the development of other types of cellulose sheets, such as saran wrap. "Cellophane" has become part of the vernacular for any transparent, thin, plastic-type sheet. Cellophane has numerous applications, including medical equipment, scientific research, and rubber and fiberglass products. More than two thousand forms of cellophane are currently produced.

After the 1960's, cellophane use declined as similar products came on the market. Environmentalists raised concerns about carbon disulfide (used to produce cellophane), which can be a pollutant if it is not properly disposed of. Cellophane itself, on the other hand, is completely biodegradable.

—*Jennifer L. Campbell*

FURTHER READING

Aftalion, Fred. *A History of the International Chemical Industry*. Philadelphia: University of Pennsylvania Press, 1991. Discusses DuPont, the invention of cellophane, and the product's evolution.

Jones, Charlotte. *Accidents May Happen: Fifty Inventions Discovered by Mistake*. New York: Delacorte Books, 1996. In addition to cellophane, the author discusses Worcestershire Sauce, ice-cream floats, dynamite, and peanut brittle. Suitable for children from third to sixth grade.

Ndiaye, Pap. *Nylon and Bombs: DuPont and the March of Modern America*. Baltimore: The Johns Hopkins University Press, 2006. A history of DuPont that discusses cellophane and the company's aggressive advertising campaign, as well as improvements made to the product. Suitable for the general reader.

Porter, Glenn. "Cultural Forces and Commercial Constraints: Designing Packaging in the Twentieth Century United States." *Journal of Design History* 12, no. 1 (1999): 25-43. Investigates the effects of society on packaging design. One detailed case study examines DuPont and its aggressive advertising and marketing campaigns for cellophane.

Rutherford, Janice Williams. *Selling Mrs. Consumer: Christine Frederick and the Rise of Household Efficiency*. Athens: University of Georgia Press, 2003. Christine Frederick was a home-efficiency expert who found many ways to save time doing housework, and she wrote a column for *Ladies' Home Journal* that shared tips and advice for other housewives. Rutherford uses Frederick's life as a case study for examining the rise of consumerism in the United States.

Stocking, George, and Willard F. Mueller. "The Cellophane Case and the New Competition." *American Economic Review* 45, no. 1 (March, 1955): 29-63. Written by two economists, this article summarizes a 1947 lawsuit against DuPont stating that the company had a monopoly on the cellophane industry. Authors explain the details of DuPont's arrangement with La Cellophane, marketing and consumer research, and sales figures for cellophane.

See also: Wallace Hume Carothers; Richard G. Drew; Margaret E. Knight.

WALTER H. BRATTAIN

American physicist

Brattain, John Bardeen, and William Shockley are credited with what has been called the invention of the twentieth century, the transistor. Because of this tiny device, personal computers, cell phones, and hundreds of other electronic devices created a new age of productivity and telecommunications.

Born: February 10, 1902; Amoy, China
Died: October 13, 1987; Seattle, Washington
Also known as: Walter Houser Brattain (full name)
Primary fields: Communications; electronics and electrical engineering
Primary invention: Transistor

EARLY LIFE

Walter Houser Brattain (BRA-tihn) was born in Amoy, China, on February 10, 1902. His father, Ross, and mother, Ottilie, married after graduating from Whitman College in Walla Walla, Washington. Ross, a teacher, accepted a job in China teaching science and math. The three were there for a short time, and the family returned to Washington. Walter grew up on a large cattle ranch just south of the Canadian border.

In the fall of 1920, Brattain enrolled in Whitman College, majoring in physics and mathematics, and four years later he received a bachelor of science degree. He claimed that these were the only two subjects in which he excelled. He went to the University of Oregon for his master's degree (1926) and to the University of Minnesota for his Ph.D. (1929). While studying for his doctorate, he worked at the National Bureau of Standards (now the National Institute of Standards and Technology) in Washington, D.C., but decided that he preferred physics to engineering. Brattain met John Bardeen in Princeton, New Jersey, while Bardeen was working to complete his Ph.D. in theoretical physics at Princeton University. Robert Brattain, Walter's brother, was a classmate of Bardeen. Walter and John became fast friends and later became lab partners.

LIFE'S WORK

Bardeen and Brattain, along with William Shockley, would invent the transistor—essentially, a solid-state version of the triode vacuum tube. Compared to the vacuum tube, the transistor was very small, had an amazingly long life, consumed little power, and did not get hot. Were such a device possible (it took years to determine that it was), it would be an extremely valuable product for the telephone industry, which used thousands of vacuum tube amplifiers for long-distance service.

Brattain joined Bell Telephone Laboratories (Bell Labs) on August 1, 1929, after receiving his Ph.D. and began work with Joseph A. Becker, a research physicist at Bell Labs. Brattain spent most of his time studying copper oxide rectifiers. The two scientists hoped that they could make an amplifier by putting a tiny metal grid in the middle of the device, much as had been done with the triode vacuum tube. This did not work, but the experience provided valuable information regarding crystals and the theory of surface states in semiconductors.

In the years before World War II, Brattain was involved with the surface physics of tungsten and later silicon. He was sidetracked during the war, devoting his energies to developing methods of submarine detection.

Following the war, he returned to Bell Labs and was soon assigned to a new solid-state group organized by the president of Bell Labs, Mervin Kelly. The head of this group was William Shockley. Shortly thereafter, Bardeen joined the group. The three were ideally suited for the project. Bardeen was the thinker: He could examine an event and go beyond common understanding to explain it. Brattain was the experimenter: He could put together any contraption needed. Shockley was the visionary: He could look beyond the experiment and determine just what it might mean for the future.

Toward the end of 1947, a period often called "the miracle month," Brattain and Bardeen were still struggling to achieve amplification out of a semiconductor device. (Shockley was off pursuing a different approach.) Brattain was conducting an experiment that would supposedly explain how electrons acted on the surface of a semiconductor, and he was having trouble with condensation. Frustrated, he dumped the whole experiment into a beaker of water—taking care of the condensation. Suddenly, there was real amplification.

Bardeen suggested that somehow a metal point be pushed into the silicon surrounded by water. However, the contact point could not touch the water; it could only touch the silicon. Brattain solved the problem by coating the metal point with paraffin and pushing it into the silicon. With this, the apparatus worked; they had achieved amplification.

Over the following weeks, changes were made, and the results continued to improve. Germanium, rather than silicon, was used. The method used to get two gold point contacts just a fraction of a millimeter apart was quite ingenious. Brattain coated the edge of a draftsman's triangle with gold foil and then carefully sliced it through at one of the points. The first point-contact transistor had been made.

For a week, the two men kept the experiment a secret. On December 23, 1947, Bell Labs' management was briefed on the invention of the first solid-state amplifier. The patent dealing with the point-contact transistor was awarded to Brattain and Bardeen, and not to Shockley. However, several months later Shockley developed his own transistor—actually a much superior one, called the junction transistor. The three men were awarded the Nobel Prize in Physics in 1956.

Life for the three after the invention of the transistor was not smooth. Shockley was difficult to work with, and Brattain soon asked to be transferred to a different lab at American Telephone and Telegraph Company

THE TRANSISTOR

The transistor invented by Walter H. Brattain and John Bardeen in December, 1947, was called the point-contact transistor. One month later, William Shockley, the supervisor of the three-man group, invented the junction transistor. All three were awarded the Nobel Prize in Physics in 1956 for the invention of the transistor. Although the construction of the two types of transistors is different, they operate in essentially the same way.

In its basic form, the transistor's function is to take electric current (electrons), send those electrons from one element to another (in the case of a transistor, the emitter and the collector), and control the flow of those electrons with a third element (the base). A large current flowing between emitter to collector can be made smaller or larger by adjusting the current to the base. The result is amplification.

One example is simple amplification of an analog signal as might be used in a radio. Radio waves are extremely small; in order to be audible to humans, the waves must be amplified many times. An incoming radio signal is received by the radio's antenna, and the tiny electrical wave is sent to the base of a transistor. The resultant signal at the collector is identical in shape to the input signal at the base, except it is about one hundred times larger. It is now possible to apply this signal to the base of a second transistor and have the signal once again amplified about one hundred times. This process is continued until the resultant signal, the tone, is audible.

In another example, called switching mode, a transistor operates in one of two states: on or off. Digital computers utilize transistors that operate this way. By utilizing other electronic components, logic functions can be performed. Of great importance is the fact that these functions can be done very fast—millions of operations can be performed each second.

The electrons flowing in a transistor do not flow in a vacuum, as they would in a vacuum tube, but rather in a solid piece of germanium or silicon; hence the name "solid state." The theory of the transistor is extremely complicated, and a total understanding requires a knowledge of quantum mechanics. The materials used to make transistors (silicon and germanium, for instance) have four electrons in their outer orbits. It is possible to dope a piece of this element with molecules of a different element and combine several such pieces with very sophisticated technology. Then, as the electrons in the orbits of the several pieces flow (and they are in constant motion), the transistor effect is created.

(AT&T), where he stayed until retiring to take a teaching position at his alma mater. Bardeen left to work at the University of Illinois, where he could concentrate on physics theory; he would win a second Nobel Prize, for his work with cryogenics, in 1972. Shockley left AT&T to form Shockley Semiconductor Laboratory in Palo Alto, California.

Impact

The transistor has been called the most important invention of the twentieth century, largely because it made personal computers possible. There were, of course, computers before the transistor, but they were large, cumbersome, expensive, and hot. Their mean time between failure was very short. Communications channels (particularly with the telephone industry in mind) were expensive to build and difficult to maintain. All of this would change with the transistor. As improvements to the transistor were made, it evolved into the integrated circuit (invented by people who joined, and then left, Shockley Semiconductor Laboratory). Integrated circuits became smaller and faster, to the point where it is now possible to place several million on the head of a pin.

Transistors and the integrated circuits they made possible opened the way for cell phones, laptop computers, handheld computers, and global positioning systems. Today, telephones are able to indicate who is calling, and emergency service systems are able to pinpoint the location of accident victims. The Internet is accessible to millions of people, making it possible to communicate with anyone in the world. Indeed, every place on earth is equidistant from every other place on earth—all thanks to the transistor.

—*Robert E. Stoffels*

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See also: John Bardeen; Seymour Cray; Nick Holonyak, Jr.; Gerald Pearson; Claude Elwood Shannon; William Shockley.

Karl Ferdinand Braun

German physicist

Braun developed the oscilloscope, which enabled researchers to see electrical waveforms in real time and was an important stepping-stone in the development of modern radars and of all-electronic television.

Born: June 6, 1850; Fulda, Hesse-Kassel (now in Germany)
Died: April 20, 1918; Brooklyn, New York
Primary field: Electronics and electrical engineering
Primary inventions: Wireless telegraphy; cathode-ray oscilloscope

Early Life

Karl Ferdinand Braun (BROWN) was born in 1850 in Fulda, a city in the principality of Hesse-Kassel, which would soon be incorporated into the militarily aggressive German kingdom of Prussia, and ultimately into the German Empire. Braun’s father, Konrad Braun, was a civil servant working as a court clerk. His mother, Franziska Braun, née Gohring, was the daughter of the elder Braun’s supervisor in the civil service.

After successfully completing the course of study in the local *Gymnasium*, or high school, Braun went to the University of Marburg to pursue a higher education. That path ultimately led him to the University of Berlin, where he earned his doctorate in 1872, writing a dissertation on the vibrations of elastic rods and strings. His work was interesting in its implications for thermodynamics, which at the time was still in its infancy and still largely confined to studies of high-temperature machines such as steam engines.

LIFE'S WORK

After completing his doctorate, Braun began to concentrate primarily on electrical phenomena. One of his earliest investigations was into the behavior of some metallic sulfide crystals, which conducted electricity only in one direction. His work would become the foundation for the development of the crystal detector, an early semiconductor device used in detecting and rectifying radio waves before the development of reliable vacuum tubes.

Over the next several years, he would move from one university to the next, always holding relatively prestigious positions in their departments of physics but never able to attain a stable appointment. That changed in 1895, when he finally returned to the University of Strassburg (modern Strasbourg), in Alsace, which at the time was part of the German Empire. He would continue to hold that position until his death and ultimately became so satisfied with it that he even turned down an offer of an endowed chair at the extremely prestigious University of Leipzig.

In the late 1890's, Braun became increasingly interested in the Crookes tube, an early prototype of the cathode-ray tube (CRT), which was a development of the diode originally developed by Thomas Alva Edison as part of research into why incandescent light bulbs were developing stains on the inside. By hanging a second element, or plate, inside the bulb, he was able to detect a current, which he named the Edison effect, but he could see no practical use for it, setting that work aside to pursue other projects with more immediate monetary rewards.

The Crookes tube modified the plate into a set of deflectors that could cause the cathode to emit a stream of electrons toward the far end of the tube, which could be coated with a phosphorescent material. The earliest forms of the CRT were instrumental in the discovery of the electron, which proved that electricity was particulate in nature rather than a fluid as experimenters as early as Benjamin Franklin had simply assumed, an assumption enshrined in terms such as "current" that were too deeply embedded in the discipline to be uprooted.

However, Braun saw additional potentials for the CRT, and by modifying it so that a fluctuating current could be imposed upon the plate voltage, he created the first oscilloscope. At last, scientists and engineers had a device that could display electrical waveforms in real time, which was extremely useful in the diagnosis of faults in complex electronic equipment. Even the basic phase reversal of alternating current (AC) could be observed on an oscilloscope, allowing engineers at power plants to see when a generator was lagging or otherwise malfunctioning.

Braun's first practical application of the oscilloscope was in radio transmission, when Guglielmo Marconi revealed that his transmitter would send signals only a few miles. By attaching an oscilloscope to the system, Braun was able to identify the upper limit on the Hertz oscillator, a key part of the antenna, by which further expansion of the spark gap actually decreased its output rather than increasing it. Braun then proceeded to design an entirely new type of antenna for Marconi's transmitter, removing the spark from the system by taking the antenna out of the transmitter circuit and having the signal be conveyed to the antenna by means of condensers, huge wire coils that transformed electricity into magnetic fields that would induce electrical current in the antenna. As a result, he was able to increase power and gain increased transmission distance in a fairly linear fashion. He also applied this discovery to Marconi's radio receiver, isolating the antenna from the detector circuits so it was less likely to pick up random static rather than the signal its user was seeking. As a reward for this breakthrough, Braun shared the 1909 Nobel Prize in Physics with Marconi.

His success with Marconi's transmitter ignited an interest in all aspects of radio transmission and detection. Braun developed a new kind of antenna that would transmit only in a single plane, unlike the earlier antennas that sent radio waves in all directions, rather like a spherical version of the ripples radiating outward from a rock thrown into a still pond. The unidirectional radio antenna was useful in sending a signal that was intended only for recipients in one particular area, for instance a military unit such as a squadron of ships at sea.

Braun also recognized the utility of radio in navigation. Although the development of the marine chronometer had greatly improved the accuracy of open-ocean navigation, its margin of error could still become deadly as ships approached dry land. Particularly if storms had thrown them off course since their last opportunity to take sun sightings and compare the local time to the reference time carried by the chronometer, ships could easily be thrown onto rocks when their navigators had placed them a mile or two away. Although lighthouses built along the coast could provide some warning for the most treacherous approaches such as Cape Hatteras or the Isles of Scilly, heavy rain or fog could obscure their lights until a ship was dangerously close. By contrast, radio waves passed untroubled through even the heaviest rain and fog. If one could establish a system of radio beacons along the shoreline, particularly near dangerous approaches and important harbor, sailors would have a readily available navigation tool no matter the weather.

In 1914, Braun became entangled in patent litigation in a U.S. court and as a result came to the United States. While he was there, he was also able to look into the various voice transmissions being pioneered by Reginald Aubrey Fessenden, Lee De Forest, Edwin H. Armstrong, and others. However, his age and resultant ill health delayed his testimony repeatedly, until the United States entered World War I in 1917. As a result, Braun was regarded as an enemy alien and prevented from returning to his native land, although his age and standing as an eminent scientist prevented any formal accusations of spying or internment.

Being trapped on the far side of the Atlantic, unable to contact his family and friends or to speak on behalf of German scientists as a result of the hostilities, was a very wearing situation for the elderly Braun, who had already experienced episodes of ill health. The final blow was a fall that broke his hip. Although he was hurried to the hospital, the injury refused to heal, leaving him bedridden. As it sunk through to him that he would never again be able to live an independent life, the will to live seeped out of him and he died in his Brooklyn apartment during the spring of 1918, with the end of the war still months away. Because the war made it impossible for his remains to be returned to his homeland, they were instead cremated so the ashes could be

THE OSCILLOSCOPE

In the earliest days of electricity, there was no way to directly display a waveform visually. Because scientists studying electrical phenomena frequently found it useful to have the waveforms displayed in visual form, early researchers laboriously hand-plotted the readings from a galvanometer on graph paper. However, rapidly changing readings could be missed, simply because of limits on human attention and reaction times. As a result, scientists developed various tools for plotting the waveforms mechanically. However, most of these devices used various kinds of pens or styli on paper, and while they did make a permanent record, they often ran into limitations related to the latency of mechanical systems.

When Karl Ferdinand Braun realized that the Crookes tube (an early prototype of the cathode-ray tube, or CRT), could be modified so that it would trace the waveform of an electrical signal across its flat end, he scored a major coup for all scientists and engineers working with electricity. Braun's oscilloscope provided them with a real-time indicator of a waveform's changes as they were occurring, which allowed researchers to observe events they might not necessarily want or be able to capture on a paper-based system.

Although Braun originally created the oscilloscope as an interesting demonstration of certain phenomena of electrical physics, he realized its practical use when radio inventor Guglielmo Marconi filed for a patent and had to reveal that his transmitter could only send a signal a dozen miles. Puzzled at this limited range, Braun contacted Marconi and as a result was able to investigate Marconi's equipment with his newly invented oscilloscope. As a result, Braun was able to identify several of the key factors that were limiting Marconi's success, in particular the loss of energy to sparking in the antenna. This collaboration led to Braun sharing the 1909 Nobel Prize in Physics with Marconi.

As the oscilloscope was adopted widely by scientists and engineers around the world, other uses for it were soon realized. Russian scientist and inventor Boris Rosing used a modified version of it to display his early television experiments, and Rosing's protégé Vladimir Zworykin would remember those works when designing the receiver for his own iconoscope television camera tube. As American and British military researchers developed radar as an air-defense technology, they used oscilloscopes modified to scan radially rather than horizontally to display the returns.

Another important use of the oscilloscope was in medical monitoring. As such devices as the electrocardiograph (ECG or EKG) and electroencephelograph (EEG) were developed to detect and display electrical activity of the heart and brain, respectively, doctors working in clinical situations often wanted to be able to see moment-by-moment activity levels rather than produce a permanent record. Thus, an oscilloscope was calibrated to show normal parameters for the physiological response being measured, so that medical personnel could tell at a glance whether a patient's heartbeat or other electrical activity was normal or awry.

Even in the digital age, the oscilloscope remained an important device, although increasingly CRT-based oscilloscopes gave way to ones using analog-to-digital conversion systems to display their readouts on flat-panel screens, generally a liquid crystal display (LCD). These solid-state digital oscilloscopes enjoy the advantages of lower power consumption, greater ruggedness, and better memory functions for the comparison of waveforms over time.

held safely until such time it was possible to transport them to Germany.

IMPACT

With the oscilloscope, Braun became the "father of the video display." The oscilloscope not only was immediately useful for physicists and electrical engineers studying the operation of circuits but also demonstrated the ability of the cathode-ray tube to display information in visual form. Thus, both Vladimir Zworykin and Philo T. Farnsworth turned to the CRT for their television receivers, and the developers of the minicomputer and microcomputer used the CRT to show data and operations. Although the CRT has been superseded by solid-state devices such as the liquid crystal display, those technologies became possible only because the CRT made television and personal computing profitable.

—*Leigh Husband Kimmel*

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See also: Edwin H. Armstrong; Sir William Crookes; Lee De Forest; Thomas Alva Edison; Philo T. Farnsworth; Reginald Aubrey Fessenden; Benjamin Franklin; Guglielmo Marconi; Vladimir Zworykin.

WERNHER VON BRAUN

German rocket engineer

Von Braun was one of the premier rocket scientists of the twentieth century. His work was responsible for Germany's V-2 rockets, several American rockets and missiles, and the Saturn V rocket that carried the Apollo astronauts to the Moon.

Born: March 23, 1912; Wirsitz, Germany (now Wyrzysk, Poland)
Died: June 16, 1977; Alexandria, Virginia
Also known as: Wernher Magnus Maximilian von Braun (full name); Baron von Braun
Primary fields: Aeronautics and aerospace technology; military technology and weaponry; physics
Primary inventions: Saturn V rocket; V-2 rocket

EARLY LIFE

Wernher von Braun (VAYR-ner fon BROWN) was born the second of three sons to Baron Magnus Maximilian von Braun, a Prussian farmer. In 1924, Baron von Braun and his family moved to Berlin when he accepted the position of Reich minister of agriculture, a position that he held until resigning in protest as soon as Adolf Hitler became chancellor of Germany. In school, the young Wernher von Braun showed an early aptitude for music, an interest that he retained for the rest of his life. Von Braun was enrolled in a prestigious French school, but he did not do well. He did particularly poorly in mathematics. His lack of interest in school led him to pursue other interests. It was at this time that he began an interest in rocketry that was to dominate the rest of his life. At age twelve, von Braun and his brother tied several sky rockets to the back of a wagon. After the rockets were lit, they propelled the wagon at a high rate of speed down a major Berlin street, bouncing off vehicles and pedestrians along the way. Despite being grounded, von Braun continued his rocket experiments. Von Braun's mother, though, encouraged his interest in rockets by introducing him to science-fiction novels and giving him a telescope.

Hoping for better performance, von Braun's parents transferred him to a boarding school at Ettersburg Castle, where he became a better student, though he still performed poorly in mathematics and physics. There, von Braun tried to read a book by rocket pioneer Hermann

Oberth. Unfortunately, he found the book to be filled with equations. He decided that he must learn physics and mathematics to understand the book. His hard work was rewarded, and he became an expert student in those areas.

In 1928, von Braun transferred to the Hermann Lietz School, another boarding school, but one well known for its technical training. There, von Braun became a mathematics tutor. Upon graduation, he moved to Berlin to receive technical training at the Federal Institute of Technology. Then, in 1934, von Braun received his Ph.D. in physics from the University of Berlin.

Life's Work

While still in school in Berlin, von Braun joined the Verein für Raumschiffahrt (VfR), the German spaceflight society. Together with other members of the group, he was able to experiment and construct increasingly powerful rockets. However, the cost of their work began to exceed what they could afford based on donations and their own funds. So, von Braun managed to secure funding from the German army in 1932 to construct even larger rockets. This money came with restrictions, though. The army wanted rockets to serve as ultra-long-range artillery. Some members of the VfR left because of this restriction. Von Braun wanted money to build rockets for space exploration, but money was not available for that. Money was available for weapons, though, and he apparently felt that the research and development for rockets used for weapons could eventually be turned toward peaceful applications.

The army wanted the rocket development work to be moved to a more secure site near Peenemünde, Germany. It was there, when von Braun was put in charge of a well-funded research team, that his work really began to take off. Von Braun began developing increasingly larger rockets, eventually resulting in the development of the alcohol-water- and liquid-oxygen-fueled Aggregat 4 (A-4) rocket. With the Nazi Party in power and war looming, the Nazis looked unfavorably on such a prominent facility as the Peenemünde rocket center being under the control of a non-party member. Under increasingly severe pressure, von Braun was finally forced to join the Nazi Party in 1937 or else have control of the facility taken from him. In 1940, von Braun was similarly given an ultimatum to either join the Schutzstaffel (SS) or be removed from his position. Von Braun relented, though he virtually never wore his uniform nor a swastika armband, and he remained critical of Nazi policies. In 1944, Hitler renamed the A-4 the Vergeltungswaffe 2 (V-2) rocket. The V-2 rocket was the first long-range military missile, capable of delivering a 2,000-pound warhead from Germany to London. The V-2 rocket accomplished this by powering itself into a ballistic arc that carried it just above Earth's atmosphere, making it the first rocket to achieve suborbital spaceflight. However, von Braun continued to promote peaceful space exploration. He was arrested by the Gestapo for comments made at a party declaring that his

The Saturn V Rocket

In 1961, President John F. Kennedy declared the goal of sending American astronauts to the Moon. In order to reach this goal, engineers needed to build a rocket far larger than any that had ever been constructed. Wernher von Braun and his team of rocket engineers had the task of designing the rocket that would do the job. The Saturn rocket family was the result of that work. The Saturn V rocket was the largest member of the family and was the culmination of von Braun's life's work. It was 364 feet tall and had a diameter of 33 feet. When fully loaded, it weighed in excess of 6 million pounds. It could carry a payload of over 250,000 pounds to Earth orbit and over 100,000 pounds to the Moon. No other rocket has yet matched this capability.

The Saturn V rocket consisted of three stages. The first stage, designated S-IC, was 183 feet long and was propelled by five massive rocket engines, each capable of providing 1.6 million pounds of thrust. The fuel for the first stage was RP-1 rocket fuel, basically a very highly refined form of kerosene. There was enough kerosene and liquid oxygen in the first stage of the Saturn rocket to fill more than fifty railroad tank cars. This propellant was burned within nearly three minutes of launch. The second stage, designated S-II, was 81.5 feet long and 33 feet in diameter. It was propelled by five J-2 engines using liquid hydrogen and liquid oxygen. The third stage, designated S-IVB, had one J-2 engine, also using liquid hydrogen and liquid oxygen as propellant. It was just under 59 feet long and 21 feet in diameter. The S-IVB stage was essentially the same as the second stage of the earlier Saturn 1B rocket.

A total of fifteen Saturn V rockets were produced. Three of these were launched into Earth orbit as test flights. Nine Saturn V rockets were launched with manned payloads to the Moon. Six of those payloads resulted in lunar landings. One Saturn V was used with its third stage modified to be the Skylab space station. The remaining two Saturn V rockets were never used, and portions of them are on display at various NASA centers.

Wernher von Braun. (NASA)

rockets would be far better used for peaceful purposes than as weapons.

Near the end of World War II, von Braun arranged for himself and several hundred other German rocket scientists to surrender to the United States. Upon their surrender, they were taken to Fort Bliss, Texas, where the U.S. Army put them to work developing missiles for the United States. Von Braun returned to Germany in 1947 to marry Maria von Quistorp. Their first child, Iris, was born in 1948. Though he was working for the U.S. Army building more weapons, von Braun continued to push for peaceful space exploration. He wrote a series of articles for *Collier's Weekly* in 1953 and 1954 expounding on the possibilities of manned space travel, space stations, and colonies in space. On April 15, 1955, Wernher von Braun became a naturalized U.S. citizen. In 1956, the Army created the Army Ballistic Missile Agency (ABMA) in Huntsville, Alabama, and von Braun was made its technical director. There, von Braun developed several more missiles, including the Jupiter missile and the Jupiter C missile.

While at ABMA, von Braun began work on plans to launch an artificial satellite into Earth orbit. However, in 1955, when the United States announced that it would launch a satellite during the International Geophysical Year of 1957-1958, von Braun's program was not selected to do the job. Rather, the Vanguard program was given priority. However, following the successful launch of two Sputnik satellites by the Soviet Union in 1957, and with the Vanguard program having difficulties, von Braun's team was given the green light to launch a satellite. They successfully launched Explorer 1, America's first artificial satellite, in January of 1958. Later that year, von Braun and ABMA became part of the newly created civilian space agency, the National Aeronautics and Space Administration (NASA).

Working with NASA, von Braun completed development of the Saturn 1B rocket, the largest rocket that had been built by the United States. He then headed the development of the Saturn V rocket, which eventually took American Apollo astronauts to the Moon. The Saturn V rocket remains the largest successfully operational rocket that has ever been built.

In March, 1970, von Braun was transferred to NASA headquarters. However, he never fit in with the Washington culture, and he felt ineffective. He retired from NASA in 1972 to begin work as vice president of engineering and development for Fairchild Industries. He was diagnosed with liver cancer in 1973 and colon cancer in 1975. He continued to work as best he could through his illness, but by the next year he was bedridden. He resigned from Fairchild on January 1, 1977, and died of cancer on June 16, 1977.

IMPACT

Von Braun was obsessed with rocketry from his early experiments with rockets as a boy. Oberth's book, *The Road to Interplanetary Space*, which he read as a schoolboy, was pivotal in influencing his choice of career in order to pursue his dream of building bigger and better rockets. His single-minded pursuit of this goal led him to become one of the most influential rocket scientists of the twentieth century. His V-2 rockets quickly became a feared weapon of war, though they came far too late in World War II to actually have much effect on the outcome of the war. His crowning accomplishment, though, was the Saturn V rocket, which was essential to the United States' manned exploration of the Moon. Furthermore, von Braun was a visionary and dreamer who truly believed that mankind needed to explore and colonize beyond Earth. He realized that education was key to successfully completing his goal. He was a champion of science education, continuing his educational activities until he became bedridden with cancer.

Von Braun was pressured into joining the Nazi party and the SS. He did not appear to share their agendas. Most likely, he joined solely for utilitarian purposes, as a means to continue his rocketry research. However, a number of people have not forgiven him for this decision, and while some have praised his integrity, others have long regarded him as a war criminal. He apparently knew that the SS was using slave laborers to build V-2 rockets, but he claims that he did not realize just how poorly they were treated and that his position in the organization was too low to influence any decisions regarding them. This claim has been disputed.

—*Raymond D. Benge, Jr.*

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See also: Robert H. Goddard; Burt Rutan; Henry Thomas Sampson; Konstantin Tsiolkovsky.

JOHN MOSES BROWNING

American engineer

Browning is history's most successful, prolific, and influential firearms inventor. His groundbreaking inventions established the basic functioning principles used in a wide spectrum of popular and seminal sporting rifles, shotguns, automatic pistols, and machine guns. These principles underlie almost all firearm designs produced and used to this day.

Born: January 21, 1855; Ogden, Utah
Died: November 26, 1926; Liège, Belgium
Primary field: Military technology and weaponry
Primary inventions: Colt .45 automatic pistol; single-shot rifle; gas-operated machine gun

EARLY LIFE

John Moses Browning was born in Ogden, Utah, to Jonathan Browning, a self-taught gunsmith and gunmaker from Tennessee. At age twenty-nine, Jonathan had moved to Illinois and converted to the Mormon Church. As a skilled gunsmith and "mechanic," Jonathan was an important contributor to the Mormons' self-sufficiency during their colonization of Utah. Jonathan was also polygamous, fathering twenty-two children with three wives. The eldest child with his second wife was John Moses Browning.

Jonathan was a talented gunmaker and inventor. He designed and built an unusual yet accurate and reliable breach-loading black-powder rifle called the "Harmonica rifle." In addition to gun construction and repair, Jonathan also tinkered with diverse and hopefully money-making projects including tool repair, brick making, and operating a tannery. Besides providing for a large family, dilettantism with projects, and inattention to business details, Jonathan proved to be an indifferent businessman. He did, however, pass on to his sons his tool skills and an understanding of firearms principles. John Moses, for example, constructed his first firearm at age thirteen. During his adolescent years, John did many of the shop's gun and tool repairs while Jonathan tinkered with his current fancy. As a result, at Jonathan's death John was the heir apparent to the family business.

Jonathan died in 1879, the year that John received his first patent. Family tradition claims that this was the upshot of a challenge by Jonathan that John should design a better breach-loading rifle than one then being repaired in the shop. The result was patent number 220,271 for a single-shot rifle that was strong, easy to use, reliable, and accurate. With Jonathan's shop, a patent, his own life savings, and his younger brothers as a workforce, John founded J. M. Browning and Brothers and began to produce the single-shot rifle.

LIFE'S WORK

As owner and manager of this new "factory," John discovered that it was difficult to maintain both quality and a profitable production schedule. Browning saw that running a gun-making enterprise was tedious and time-consuming. Browning was saved from these frustrations by the general manager of the Winchester Repeating Arms Company, Thomas Gray Bennett. After seeing one of the single-shot rifles, Bennett traveled in 1883 to Ogden to purchase production rights. As with most of his later designs, Browning sold the rights for a lump sum rather than for royalties, a deal that spared him from production work and made the purchasing company responsible for raising capital, running production, and assuring quality—which relieved Browning from the niggling details that interfered with inventing. Fortuitously, Browning had also just completed a design for a lever-action repeating rifle that was a considerable improvement over the existing Winchester action. Bennett's purchase of this new rifle, manufactured as the Winchester 1886 lever-action repeating rifle, established a relationship in which Browning became the primary designer of Winchester rifles.

Browning's inventions coincided with a revolutionary period in the evolution of firearm designs. The American Civil War had seen the new technology of fixed ammunition become popular, and firearms using fixed ammunition became increasingly common during the 1870's. Fixed ammunition is the combination of a bullet, gunpowder, some kind of primer, and a container as a single unit. Firearms operate by the burning of gunpowder that generates gases that propel the bullet. During this period, most of the fixed ammunition came with a metal case, usually made of brass. Brass was used because it is a soft and flexible metal that can easily stretch under the stress of heat and pressure from the gases generated by the burning gunpowder. The expanded brass forms a tight seal at the breach that prevents gas from spewing back into the shooter's face. This tight seal also results in increased pressures that allow less powder to give smaller projectiles better velocity, accuracy, and impact. Before the creation of fixed ammunition, loading required loose powder to be poured into the barrel through the muzzle, after which the ball or bullet was then seated with a ramrod. The breach was sealed to ensure no leakage of gas, but the end result was a loading and firing process that was slow, cumbersome, and prone to misfires. With reliable fixed ammunition, weapons could be conveniently loaded at the breach, and their spent cases could be rapidly ejected. Thus, fixed ammunition made repeating firearms feasible.

As long as muzzle-loading was the norm, firearm design remained generally stagnant. Once fixed ammunition was introduced, inventors designed systems like the lever action for rapid reloading, followed eventually by actions that were actuated and powered by the same gases used to propel bullets. A significant factor in this firearm development was the introduction in the 1880's of nitrocellulose-based gunpowder called "smokeless powder." Smokeless powder's different burning characteristics—most noticeably a longer and more consistent burn time—enabled designers to create firearms whose actions would be powered by the gases produced as the bullet passed down the barrel. Browning's great fortune was to be born during this time of change, so that he could invent systems like lever actions, pump actions, recoil actions, and gas-operated actions that could harness these new technologies. As a result, he designed 128 separate patents for actions that established the basic principles used in sporting and military firearms used across the world.

While Browning was a hard worker and designer, he did not work alone. His younger brother Matthew and his son John eventually added to some of John's designs both as designers and especially as testers. This was necessary because of John's method of designing. When an idea occurred to him, he immediately roughed out a working model to test. He did not make drawings and plans until he had a working prototype. Field testing of his designs was therefore of considerable importance. Browning created many outstanding designs, but they were optimized for function and not for mass production. Thus, when a company like Winchester purchased a Browning design, they often had to take out patents of their own for modifications to Browning's designs that would facilitate production processes.

Browning designed these operating systems as inspiration struck him, and when he had a working model in hand he would then approach a company to sell them manufacturing rights. Through that method, he eventually came to work with most of America's big arms companies. For a period of twenty years, he sold his creations to Winchester, during which time all of Winchester's new products were Browning designs. Ultimately, to protect its market share and to prevent competitors from getting new Browning actions, Winchester purchased but never produced thirty-four different Browning designs. When, however, in 1902 Winchester refused to buy Browning's new design for an automatic shotgun, Browning severed the relationship and sold the rights for this and other shotgun designs to Remington Arms. In a similar fashion, Browning sold his designs for automatic pistols to Colt's Patent Fire Arms Manufacturing Company and the European company Fabrique Nationale (FN), located in Herstal, Belgium. Browning sold his machine gun designs to Colt. During his life, Browning's patents came so rapidly that at one point he was applying for a new patent about every three months. Nevertheless, few of his designs are thought of as Brownings by users because the production companies sold weapons by their company brand names. Such famous firearms as the Winchester 94 lever-action rifle, the Colt .45 automatic pistol, and the Remington Model 11 shotgun are all Browning designs.

IMPACT

Browning was an independent inventor who grasped the firearm fundamentals taught by his father and had an intricate knowledge of the inner workings of mechanisms. When these skills were combined with a close attention to firearm principles and an inventive mind, the result was a plethora of firearms inventions. These inventions were focused on practicality and reliability and resulted in some of the best-known firearm designs of the nineteenth and twentieth centuries. Browning's designs included rugged and reliable lever-action rifles and shotguns, pump rifles and shotguns, automatic shotguns, recoil-operated automatic pistols, and machine guns. Among the best-known of Browning's designs is the Winchester 94 lever-action rifle, once touted as America's most popular hunting rifle. Among shotguns, the Remington Model 11 shotgun and superposed shotguns are seen as some of the best shotguns ever created. The Colt .45 automatic pistol, adopted by the U.S. Army, was used until 1985, while the .50-caliber M2 heavy machine gun that was adopted in 1921 and modified in 1932 is still in use. Military aircraft flying from the 1930's through the 1960's used Browning-designed .30- and .50-caliber machine guns and 37mm machine cannons. Because so many of these designs were seminal in nature, most firearms designs to this day derive from the principles identified and harnessed by John Moses Browning.

—Kevin B. Reid

THE COLT .45 AUTOMATIC PISTOL

While John Moses Browning's initial designs were focused on turning a principle into a working firearm, the finished products were characteristically simple, robust, reliable, and functional. A good example of this is the Colt .45 automatic pistol, officially known as the "U.S. Pistol, Automatic, Caliber .45, Model of 1911," which is commonly called the Colt Model 1911. The Model 1911 was an improved version of the Colt Model 1900, the first autoloading pistol produced in America.

The Model 1911 used a short-recoil system, in which the barrel and breach travel together a short distance to allow the bullet to pass the muzzle before the breach opens. This process is accomplished with a simple linkage between the barrel and the frame of the pistol. The breach is housed in a slide that moves backward and forward on rails. When a round is fired, the barrel and breach are initially locked together. The force of recoil forces the cartridge case back against the face of the breach. This drives the barrel and slide together for a short distance until the pivoted linkage between the barrel and the frame unlocks and disengages the barrel while the slide continues rearward. During this motion, a simple extractor grabs the empty cartridge case. As the slide continues backward, it compresses a recoil spring, cocks the hammer, and when it stops, ejects the empty cartridge case. Pressure from the recoil spring then pushes the slide forward. As it goes forward, the slide pushes a new round from the magazine into the chamber, the barrel pivots upward, and the breach locks into place. When the trigger is pulled again, the hammer falls, hitting the firing pin to fire the next round and initiate the cycle again. The mechanical elegance of this design is that each action performs multiple tasks.

The design of the Model 1911 coincided with the end of the Philippine-American War, in which U.S. troops faced natives who often continued to fight after sustaining numerous hits from lighter-caliber pistols. As a result, Browning chambered the new pistol for the .45 ACP (automatic Colt pistol) round. By combining a powerful round with a robust frame and a simple operating system, Browning created a weapon that was demonstrably effective and reliable in field conditions. This design was adopted by nations worldwide, including the United States, where it was issued from 1911 to 1985. The essential system used in the Model 1911 was also similar to later Browning automatic pistol designs such as the Browning Hi-Power, manufactured by FN. These two designs have served in armies in almost every Western nation as well as those nations supplied by the Western powers.

Further Reading

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Iannamico, Frank. *Hard Rain: History of the Browning Machine Guns*. Harmony, Maine: Moose Lake, 2002. A good introduction to the variety of models and modifications of Browning's .30- and .50-caliber machine guns.

Miller, David. *The History of Browning Firearms*. Guilford, Conn.: Lyons Press, 2006. A nicely illustrated introduction to the most significant and popular of Browning's firearm designs. Chapters organized by firearm types provide an understanding of the sheer number and diversity of Browning's designs.

See also: Samuel Colt; Sir James Dewar; Richard Gatling; Hudson Maxim; John T. Thompson.

William Bullock

American machinist

Bullock's invention of the web rotary printing press, with its increased speed of operation and efficiency, revolutionized the printing industry.

Born: 1813; Greenville, Greene County, New York
Died: April 12, 1867; Philadelphia, Pennsylvania
Primary field: Printing
Primary invention: Web rotary printing press

Early Life

William Bullock was born in 1813 and became an orphan at the age of eight when his father died; an older brother took over raising him. Early on, Bullock developed an interest in mechanics, and he spent his spare time reading on the subject. At the age of nineteen, he married Angeline Kimball in Catskill, Greene County, New York, and two years later he had his own business. In 1835, his first child, a son, was born. During this time, Bullock was not only operating his own machine shop but also experimenting with ideas for improving the traditional but tedious methods and equipment still in use in agriculture and construction. His first practicable invention was a shingle-cutting machine. Between 1838 and 1839, he traveled as far as Savannah, Georgia, to market the device, with no success.

Bullock went to New York City looking for more lucrative, satisfying work. His family was growing, with four sons and two daughters born between 1835 and 1847; his first son, however, had died at age two. While working in New York, Bullock designed several devices, most of which were related to agriculture. One was a lathe-cutting machine. Another was a cotton and hay press. Cotton and hay were important crops at that time, and farmers had to transport them over long distances to sell them. To make the crops easier to handle and transport, Bullock designed a press that could compress deseeded cotton and loose, bulky hay into manageable, compact bales, which the machine was also capable of tying together with wire or heavy twine.

Bullock also invented a grain drill, which was awarded a prize from the Franklin Institute of Pennsylvania in 1849. The device had a series of separate round disks that cut little trenches in prepared soil. From its seed hopper, it sent seeds through tubes into the trenches. Spike-toothed drags pulled the soil back into the trenches to cover the seeds. This invention eased the backbreaking labor of planting.

Life's Work

By 1850, Bullock and his family were living in Philadelphia, where he was editor of a newspaper, *The Banner of the Union*. Many of the existing printing presses had a flatbed construction and required considerable time and labor for a fairly limited circulation. Bullock began designing a hand-cranked wooden press, to which he later attached an automatic paper feeder. This device would become a crucial component of his most well-known invention, the web rotary printing press.

After Bullock's wife died in 1850, he moved his family back to Greene County, where he soon married Angeline's sister Emily. In 1853, when he became editor of a Whig Party paper, *The American Eagle*, his wife gave birth to a daughter, the first of six children they had together. Bullock continued to work on improving the printing press. He had an even greater incentive to develop an efficient printing press when the man who printed the Whig paper sold his business to a man who refused to print Bullock's paper. Determined to keep his paper going, Bullock built a wooden flatbed press with a self-feeder and began printing his paper himself.

By 1856, Bullock was ready to move on from Greene County. He sold his newspaper and moved to Brooklyn, New York, in 1857, where his son William was born that year. Bullock continued to work on improvements to his printing press, determined to make a machine that could not only print accurately and rapidly but also self-adjust and automatically feed paper. He sought to design a press that could print on both sides of a paper sheet. In 1858, when he felt that he had perfected certain aspects of his machine, he took out a patent on his automatic paper feeder.

Bullock moved to Pittsburgh in 1860, finally satisfied with his machine, which was called the web rotary printing press. Improving on Richard March Hoe's 1840's rotary press, Bullock designed his press to feed paper automatically instead of by hand, print on both sides of the paper, and cut and fold the sheets. His machine, a markedly improved press that made the printing process faster and less labor-intensive, could print as many as 12,000 sheets per hour. Newspaper publishers were quickly interested in the new press. In 1860, Bullock was called on to design one for the national publication *Frank Leslie's Illustrated Weekly*, and he built a complete working model for the *Cincinnati Times*.

Bullock went to England in 1862 to secure a British patent for his press, which was granted that year. In 1865, he built an improved cylindrical rotary printing press in Philadelphia that used a roll of continuous paper. This machine needed only three workers to operate it. Bullock continued to make modifications to his machines, until they could print as many as 30,000 sheets per hour.

On April 3, 1867, in Philadelphia, Bullock was working on one of his new presses that was to be used to print the *Public Ledger* newspaper, the city's most popular paper. As he was making an adjustment to the machine, he tried to kick one of the motor driving belts onto a pulley, but he miscalculated. His right leg was caught in the mechanism and badly crushed. Before he could be rescued from the machine, he suffered other injuries that

THE WEB ROTARY PRINTING PRESS

Of William Bullock's several inventions, his web rotary printing press is by far his most significant and enduring. Though several other men made improvements on the press both before and after Bullock, the innovations he made in the nineteenth century were incorporated into the printing process well into the twentieth century. The printing press of Johann Gutenberg in the fifteenth century set the format for presses until the 1840's, when Richard March Hoe changed from the flatbed to the faster rotary press and used steam power instead of manual labor or the foot treadle to operate the mechanisms.

Bullock improved on Hoe's invention, which, though more advanced than Gutenberg's, still printed only one page at a time using a back-and-forth motion of the type bed. Bullock conceived of a machine that had two pairs of cylinders. Two stereotype (or type) cylinders held the raised letter type; two impression cylinders pressed the paper against the type to print the copy or images. Bullock's early machine moved the sheets of paper on tapes to the impression cylinder, which pressed the paper against the inked type. Later, he devised a way for the paper, in strips measuring five or six linear miles, to be rolled on huge rollers. The paper would pass through a spray to moisten it before printing, and it would be fed into the printing process.

As the type was printed on the roll paper, which was called a web, Bullock fashioned a mechanism that would cut the paper from the continuous roll by using a serrated knife attached to the cylinders. The knife, designed so that it rarely needed sharpening, cut the paper with fast strokes into newspaper page sheets. Once cut, the sheets were moved along by grippers and tapes to be delivered on belts and grabbed by automatic metal fingers as each sheet left the final printing cylinder. The press was also capable of folding the sheets into the final format. The earliest versions of the sheet cutting and delivery system were somewhat unreliable, but Bullock soon ironed out the problems. The improvements he made to his machine soon compelled other printers to use his press.

The increased speed of Bullock's press, its efficient use of the continuous roll of paper, and several other innovative changes he made eliminated the tedious hand-feeding of paper. When the stereotype printing process was invented, the rotary press process became even better. With it, type was produced in a flexible mold made of papier-mâché and could thus be bent to fit around the cylindrical forms that Bullock's press used. As a result, the web rotary printing press made it possible for newspaper publishers to produce more issues at a faster rate at less cost and for greater profit and popularity. Bullock's press was the beginning of the modern-day web-fed newspaper press.

would hamper his recovery. Gangrene developed in his leg, and amputation was considered the only option. He went in for the operation on April 12 and died during the procedure.

Bullock was buried on the North Side in Pittsburgh in the Union Dale Cemetery. Though he did not live long enough to enjoy the fruits of his inventions, he had passed on to a trusted workman and confidant many of his ideas for further improving his printing press. Because of that, modifications continued to be made to his presses, making them some of the most successful machines of the era.

IMPACT

Bullock's invention of the web rotary printing press marked the beginning of modern newspaper publishing. His machine achieved significant speed, and its automatic paper feeder using a continuous roll did away with the labor-intensive hand-feeding used by previous printing presses. The principles that form the basis of his innovative press were widely adopted for book and newspaper publishing for decades, until the second half of the twentieth century, when the computer caused yet another revolutionary change.

—*Jane L. Ball*

FURTHER READING

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Thomas, Isaiah. *The History of Printing in America: With a Biography of Printers and an Account of Newspapers*. 2 vols. Whitefish, Mont.: Kessinger, 2008. Written by a leading early nineteenth century publisher and based on his personal research and knowledge of printers from 1640 to 1800, the book offers an important history of the printing "industry" of which Bullock was part.

See also: Johann Gutenberg; Richard March Hoe; Ottmar Mergenthaler; Jethro Tull; Eli Whitney.

ROBERT WILHELM BUNSEN

German chemist

Bunsen was involved in devising a laboratory burner that is named for him. Using the Bunsen burner to heat substances, he helped develop a spectroscope for identifying elements. He also discovered new methods to analyze gases and was a pioneer in the area of photochemistry.

Born: March 31, 1811; Göttingen, Kingdom of Westphalia (now in Germany)
Died: August 16, 1899; Heidelberg, Germany
Also known as: Robert Wilhelm Eberhard Bunsen (full name)
Primary field: Chemistry
Primary inventions: Spectroscope; Bunsen burner

EARLY LIFE

Robert Wilhelm Bunsen (RAH-burt VIHL-hehlm BUHN-sihn) was born in Göttingen, Kingdom of Westphalia (now in Germany), in 1811. He was the youngest of four sons from the marriage of Augustine Friedericke Gunsell and Christian Bunsen, who was the chief librarian and professor of languages at the University of Göttingen. Robert studied chemistry at Göttingen and received his doctorate at the early age of nineteen.

After graduating, he traveled throughout Europe on a government grant in the early 1830's. He met some of the leading scientists of the time, attended lectures given by prominent chemists, and established friendships and professional contacts that he would later draw upon when his own career became established.

In 1834, Bunsen returned to Göttingen to take a lecturing position at the university. His chemical research involved studying the element arsenic and its compounds, which were foul-smelling and poisonous substances. This was difficult and dangerous work, as the early laboratories had no ventilation fans to remove toxic gases. During this time, Bunsen discovered that an iron oxide compound was an effective antidote for arsenic poisoning.

Bunsen continued to work with dangerous arsenic compounds after he moved to the University of Kassel, in Germany, in 1836. To protect himself from the toxic fumes, he constructed a glass face mask that was attached to a long tube extending out a window for fresh air. Tragedy struck the chemist during an experiment when one of the compounds exploded. It shattered the mask, sending glass slivers into his right eye and blinding him. Bunsen stopped working on these dangerous compounds but was undeterred in his pursuit of scientific knowledge.

Life's Work

As a professor at the German University of Marsburg from 1839 to 1851, Bunsen turned to gas analysis and a study of blast furnaces used to manufacture iron. He was able to demonstrate that the iron ore industries in Germany and England were losing considerable fuel in their waste gases. By following Bunsen's advice, the companies were able to save considerably in their coal usage. He also recommended recycling gases to recover valuable by-products (such as ammonia) that were being lost. Bunsen went on to study other properties of gases such as their specific gravities and their absorption by liquids. On this topic, he would eventually publish his only book, *Gasometrische Methoden*, in 1857.

In 1852, Bunsen replaced the German chemist Leopold Gmelin as chemistry professor at the University of Heidelberg. A new laboratory building was constructed for Bunsen, and facilities included a system for piping coal gas into the building, to be used as fuel for laboratory burners. However, the burners of the day were very inefficient and could not generate high temperatures. They also burned with a yellow luminous flame that produced considerable smoke and soot. Bunsen (along with two coworkers, Peter Desaga, an instrument maker, and Henry Roscoe, a student) designed a more efficient burner consisting of a metal tube attached to a supporting base. A gas inlet at the bottom of the tube allowed the gas in, and holes drilled in the burner's tube allowed the gas and air to mix in just the right proportion before combustion. The result was a nonluminous (pale blue) flame that was cleaner and hotter. A sliding metal cover over the holes allowed the flame to be controlled.

With Bunsen's growing reputation as a fine experimentalist and teacher, the University of Heidelberg attracted the best students in Europe as well as other illustrious scientists of the period. In 1859, Bunsen began collaborating with the Prussian physicist Gustav Kirchhoff.

Robert Wilhelm Bunsen. (Popperfoto/Getty Images)

Bunsen had observed that compounds containing metals gave off specific colors when heated in the hot flame of his Bunsen burner. For example, sodium chloride (ordinary table salt) produced a brilliant yellow colored flame, as did other compounds of sodium. This meant that metals could be detected by studying the flame colors produced when they burned. As a result, Bunsen went on to discover two new elements, the somewhat rare metals cesium and rubidium, in 1861.

A century before Bunsen's work, Sir Isaac Newton had shown that passing white light through a triangular glass prism could separate it into the visible colors seen in a rainbow. Working with Kirchhoff, Bunsen constructed a device that could analyze the light emitted from burning elements. In 1859, the two made a primitive spectroscope and used it to study the light emitted from burning metals in the hot Bunsen burner flame.

When passed through a prism in the spectroscope, the light was broken down into its constitute colors and appeared in the form of a series of lines. The pattern of lines was unique for each element, and Bunsen had found a chemical analysis method to identify elements. This discovery led to a new field of science called spectroscopy.

THE SPECTROSCOPE

Prior to the discovery of the spectroscope, chemical tests were used to identify each of the known chemical elements. As an increasing number of elements were being discovered during the nineteenth century, the spectroscope became a useful tool to quickly characterize elements since each has a unique chemical "fingerprint."

This fingerprint appears in the form of dark lines, representing absorbed light, as well as a series of colored lines from the emitted light when elements or compounds are heated to a high enough temperature. For example, lithium produces a red light, copper is green, and potassium is violet. To the eye, this light appears to be composed of just one or two colors. However, when passed through a prism and focused with a set of lenses, the light emitted from a burning element can be broken down into a series of distinct lines. The existence of these lines had previously been observed in sunlight, but their origin was uncertain.

Robert Wilhelm Bunsen and Gustav Kirchhoff enclosed their device in a box to prevent interference from other sources of light and attached a viewing telescope to see the lines. Their early version of the spectroscope proved to be a satisfactory way to analyze flame colors. The technique proved to be sensitive for very small sample quantities and could detect microgram amounts of many elements. It would later be determined that the line spectra could be related to electron transitions in atoms.

Bunsen also used this technique to study light from the Sun and suggested the instrument could be used to identify the solar composition as well as light from more distant stars. In 1888, the spectroscope was available commercially.

Bunsen's interest in light also led to research in photochemistry, the study of chemical reactions which are initiated on exposure to light. He studied the reaction between the gaseous elements hydrogen and chlorine, and he showed that the extent of reaction depended on the amount of light the mixture was irradiated with. He also had an interest in electricity and developing new batteries. He invented the Bunsen battery in which he replaced expensive platinum electrodes with cheaper carbon and zinc.

In addition to his fine experimental skills, Bunsen was highly regarded as a teacher. He would often spend the entire day in the laboratory working and teaching beside his students. He never married, and his life was centered on his research and his students. Many of them, such as Dimitry Ivanovich Mendeleyev, who is generally credited for organizing the modern periodic table of elements, would themselves go on to become famous. Bunsen died peacefully at the age of eighty-eight.

IMPACT

The Bunsen burner became an important tool in all chemical laboratories. It provided students and researchers with a high-temperature flame needed to perform many new reactions, tests, and analyses. Bunsen's other inventions such as the filter pump, vapor calorimeter, photometer, and effuser were also used as experimental tools. The Bunsen battery helped other scientists in their areas of electrochemical research. With its inexpensive carbon and zinc electrodes, it could be considered an early precursor of the modern alkaline battery.

Although Bunsen is known mostly for the burner named after him, his work on the light emitted from burning elements in a flame led to the development of the spectroscope. This had enormous impact in chemical analysis and the discovery of new elements. Shortly after Bunsen discovered cesium and rubidium, William Crookes of England used the spectroscope to discover the metal thallium. Four other elements, indium, gallium, scandium, and germanium, were subsequently found by this method. In 1868, spectroscopic analysis of the solar spectrum revealed the presence of helium in the Sun, the only element to have been detected on a nonterrestrial body before being discovered on Earth. Studying the light from distant stars became a standard technique for identifying their elemental composition.

The ability to produce colors in the high-temperature flame of a Bunsen burner became an important teaching tool. Detecting and distinguishing metals by their flame colors became a common laboratory exercise in most basic chemistry classes. The aesthetic quality of flame colors was also incorporated into the fireworks and other industries. With various metal compounds mixed with gunpowder, colorful fireworks and skyrockets have delighted crowds around the world. Other applications of elements in colored lights include neon in signs, the yellow glow of sodium vapor used to illuminate highways, and the bright red of strontium in emergency flares.

—*Nicholas C. Thomas*

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See also: Sir William Crookes; Joseph von Fraunhofer; Heike Kamerlingh Onnes; Dimitry Ivanovich Mendeleyev; John Tyndall.

LUTHER BURBANK

American horticulturist and botanist

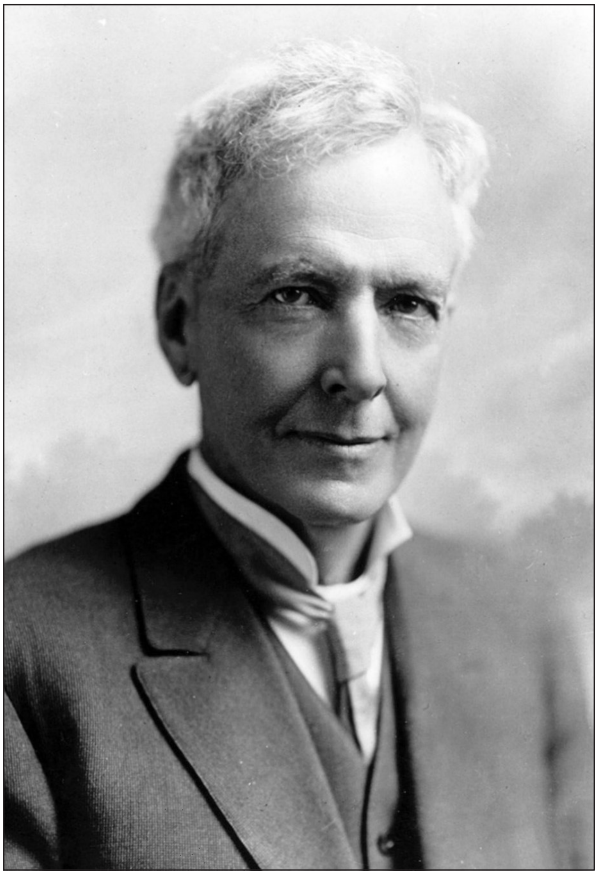
Not educated as geneticists are today, Burbank considered himself a plant breeder. He made important innovations concerning many garden plants and did pioneer work in the development of the true-breeding species hybrid.

Born: March 7, 1849; Lancaster, Massachusetts
Died: April 11, 1926; Santa Rosa, California
Primary fields: Agriculture; horticulture
Primary inventions: Russet Burbank potato; plant breeding

EARLY LIFE

Luther Burbank was the son of Samuel Walter Burbank, a farmer from Lancaster, Massachusetts, and Olive Burpee, from the same family that produced the well-known seed grower W. Atlee Burpee. Olive also loved gardening and was skilled at making things grow. Luther was a small, slightly built boy who preferred reading to physically demanding activities, although he did enjoy ice skating. As a young boy, he developed his interest in plant breeding from watching his older brother George grafting apple trees. Shy and reticent, Luther showed his penchant for invention at the age of sixteen when he made a wall clock and also a set of dumbbells for his high school gymnasium.

After his elementary schooling, Burbank entered Lancaster Academy in the fall of 1864. The academy was



Luther Burbank. (Library of Congress)

regarded as a preparatory school for universities such as Harvard and Yale, but Luther completed only four years of the five-year program and did not attend college. To a large extent, he educated himself. His favorite authors were Charles Darwin, Henry David Thoreau, and Alexander von Humboldt. He referred to these three as his "book influences." The book that intrigued him most was Darwin's *The Variation of Animals and Plants Under Domestication* (1868).

A short period of medical studies under a local doctor did not satisfy him, but he yearned for the opportunity to grow plants. He was able to purchase a seventeen-acre field in the local area in 1871. It had unusually fine soil for New England, and he soon began truck gardening. At this point, he undertook this profession less as a business than as an opportunity to make experiments in the culture of plants.

The Russet Burbank Potato

Luther Burbank worked before the period in which horticultural discoveries could be patented. Therefore, the patents awarded him after his death do not describe his procedures in detail, nor do the field notes that he made give the kind of details that facilitate a step-by-step explanation of his breeding practices. One of his most famous discoveries came very early in his career, while he was still working in Massachusetts. His development of the potato that came to be known as the Russet Burbank exemplifies his characteristic way of working. His aim here, as generally, was down-to-earth production of improved plants that served to nourish humans and satisfy their desires for beauty.

As he admitted, his work on the potato involved a stroke of good fortune. Growers of potatoes knew that potatoes, which are normally propagated by planting the "eyes" that grow on the tubers at some point after they are harvested, sometimes will generate seed pods on the potato skin. This development is quite rare, however, and the seed pod that Burbank found on an Early Rose potato was the first and only one that he ever encountered. The Burbank potato owed its existence to this rare development. What separated him from all the farmers who had witnessed seed pods on potatoes was his careful application of Darwinian theory, his curiosity, and his intuition.

From this pod he carefully raised twenty-three seedlings; from the most flourishing of these, he grew what came to be called the Burbank potato. He gathered twenty-three of these small seedlings and isolated the best ones, and the potato that came to be called the Russet Burbank was a "sport," or unusual deviation, from one seedling—one that in this case grew unusually well. Because Burbank understood the process of natural selection as elaborated by Charles Darwin, he knew how to proceed. The forces of nature would sometimes isolate, and thus create the opportunity for, favorable variations in the offspring of living plants and animals. Burbank could do this in his garden because he could anticipate this modification of offspring. As Burbank often noted, it was not simply recognizing the possibility of how a better potato or other plant might be produced but a long process of tending the improved version through successive generations thereafter that brought about success.

The Burbank potato became a principal crop in Idaho and now is often called the Idaho potato. It is difficult to determine which is the most popular variety of potato today, but this one certainly remains one of the most popular and has been found particularly well suited to one of America's favorite food items: French fries. The russet potato—like many other fruits, vegetables, and flowers developed by Burbank—remains a great favorite many decades after his death.

Life's Work

Like many other gardeners, Burbank observed that plants even in the same row grow differently, some being clearly superior to others. Grasping the importance of Darwinian thought and applying it to plant breeding, he began to stimulate modifications that nature might or might not bring about over centuries. Although Burbank's seventeen acres were very good land for New England, Burbank knew that California provided far greater opportunities for a plant breeder. In 1875, when he was only twenty-six, he moved to Santa Rosa, California, a place he described as "the chosen spot of all this earth." In California he could generate throughout the year the conditions that would allow him to make improvements to many varieties of plants.

Burbank's early and famous work on the russet potato is discussed in the accompanying sidebar. He spent much of his time and patience on fruits and flowers. His aim was to improve plants by applying the principles of natural selection and to achieve new varieties by grafting and crossing plants that he acquired from sources both domestic and foreign. He claimed that he could conduct as many as three thousand experiments at one time and that from the tens of thousands of varieties that he crossbred, hundreds were successful. He was credited with over eight hundred new varieties of plants.

One of his favorite trees was the plum tree. In the 1880's, he gathered plum seedlings from Japan and many from European and American sources. The varieties that he developed include the Wickson, Golden, and Satsuma, the last based on a Japanese plum. He developed one variety of plum without pits. Working with many sweet plums that were particularly suitable for drying into prunes, he greatly extended the making of prunes. He crossed plums and apricots and developed the plumcot tree.

Berries were another special interest. Burbank made many crosses of raspberries, blackberries, and dewberries over several decades to combine the virtues of each. He summed up this work in an eight-volume work on small fruits in 1921. Among his most celebrated flowers is the Shasta daisy, which he developed by crossing American and European varieties of field daisies and crossing the resulting hybrid with a Japanese daisy. One of his unusual inventions that exemplified the practical nature of his work is a thornless cactus, produced as food for cattle on desert ranges with limited vegetation.

At a 1909 meeting of the American Breeders' Association, Burbank spoke on "Another Mode of Species Forming," a rather vague title that set forth ideas on "the true-breeding species hybrid" that was little understood by breeders at the time. He emphasized not the mere crossing and selection but what he called "the real work" of sustained attention to successive generations of plants.

Aside from his lack of a scientific background, Burbank was faulted by his critics for several of his practices. He failed to report his activities to horticultural or scientific meetings, and he did not submit articles to scientific journals for publication. He did not describe his plants in a scientific way with proper Latin designations but in the manner of a nurseryman writing for the general public. He was criticized for his self-promotion and his sometimes exaggerated claims concerning his accomplishments. He could be careless with numbers, once referring to having planted four thousand *varieties* of seedling potato when he had actually planted that number of *individuals*. He enjoyed the fame that he achieved and did not bother to correct the misleading information of the sort that often circulates when people of limited knowledge recount the achievements in complicated fields of endeavor.

He disappointed his customers also, who sometimes could not approximate in their gardens the results that he obtained in Santa Rosa, his optimum "chosen spot." Generally, however, his perseverance over a career that lasted fifty-five years resulted in improved fruits and flowers that have remained favorites with gardeners throughout the world.

Burbank was a private man and stubbornly resisted visitors when he was working. He married twice, to Helen Coleman in 1890 (that marriage ending in divorce six years later), and to Elizabeth Waters in 1916. She survived him. He had no children with either of his wives.

IMPACT

The impact of Burbank's work has been substantial. His enormous popularity aroused jealousy among his compatriots, most of whom had professional training far beyond his own. He began his work before genetics became a recognized science, but long before his career was over he alienated scientifically trained geneticists, whose harsh assessments were sometimes justified. There is no doubt that with more training he would have understood why his unsuccessful attempts, such as his inability to produce a yellow sweet corn, were failures. Although he did not lie about his achievements, he tended to exaggerate them. He certainly was not what many people believed him to be: the plant breeder of all plant breeders.

On the other hand, the institutions that were formed in his name, the Luther Burbank Press, which published his writings, and the Luther Burbank Company, which sold his products, were important influences on his profession. These successes made scientists realize that organizations could be formed to promote biological advances and legislatures and foundations enlisted. For ordinary consumers, Burbank's name was magical. People who recognized horticultural contributions would be more inclined to support such endeavors. Specifically, his work on tree breeding encouraged the U.S. Department of Agriculture to enter into the improvement of forest trees. The general public, unconcerned about how "unscientific" he was, appreciated the plants that he developed.

—*Robert P. Ellis*

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See also: George Washington Carver; Joseph Monier; Jethro Tull.

WILLIAM SEWARD BURROUGHS

American bank clerk

Burroughs invented, produced, and sold the first practical adding machine. It was the first key-operated calculator that printed entries and sums. His work also led to the creation of a company that became the market leader for decades.

Born: January 28, 1855; Auburn, New York
Died: September 15, 1898; Citronelle, Alabama
Primary field: Business management
Primary invention: Adding machine

EARLY LIFE

William Seward Burroughs was born in Auburn, New York, on January 28, 1855. His father, Edmund Burroughs, was a machinist, inventor, and tool manufacturer. During his childhood, William tinkered in his father's machine shop. At the age of fifteen, William began working as a bank clerk. Many historical accounts tell of the young Burroughs's long, tedious days of calculation at his job, which he held for several years. However, records show that he also worked as postal clerk, box maker, and planer in Auburn. Burroughs himself told such tales in early interviews. It is probable that this story would have helped sell machines to what he saw as the primary market—banks.

In the late 1870's, Edmund Burroughs moved to St. Louis. William had been urged to move to a warmer climate, and he followed his father with his family in 1882. William had married Ida Selover in 1879, and they eventually had four children. Their grandson, William S. Burroughs, became the famous Beat writer. After moving to St. Louis, William worked various jobs that gave him experience in manufacturing. He invented various items, including a folding chicken coop, before concentrating on designing an adding machine.

LIFE'S WORK

In St. Louis, Burroughs worked for a time in his father's machine shop, where he met many inventors, including possibly Frank Stephen Baldwin, who had invented a calculator mechanism (1872), which Burroughs may have seen. Burroughs's goals for his machine were to speed up the process of calculation, make it more accurate, and to provide a written, or permanent, record of financial transactions. His original idea was for a large desktop machine, but he also wanted to automate an accounting clerk's function.

Burroughs went through many ups and downs while he worked on his machine, sometimes having to interrupt his work to earn money another way. His health suffered at times, as he worked late into the night and often into the early morning. Burroughs eventually met some St. Louis businessmen who were interested in his ideas for the adding machine. In 1884, Thomas Metcalfe and Richard M. Scruggs of the St. Louis dry goods firm Scruggs, Vandervoort, and Barney invested in Burroughs's project. Burroughs used the funds to rent bench space in the workshop of Joseph Boyer, an inventor.

Burroughs built his first machine that year and filed for a patent in 1885. His patents were the first in what would become a common patent class of the "adding and listing machine." Burroughs's first machine printed only the final totals and not the numbers entered. In 1886, he filed another patent for a machine that printed both the numbers entered and the results. Both patents were granted on the same day in 1888. In the meantime, Burroughs, Metcalfe, Scruggs, and St. Louis merchant William Pye organized the American Arithmometer Company.

Burroughs's backers may have pressured him to rush the machines to market, and the devices did not hold up well under daily use. These machines proved impractical. The force with which the operator pulled the handle on the machine could change the results. Burroughs reportedly took this first set of defective machines and threw them out the storeroom window. Within a short period of time, he had discovered the answer to the problem. He used a dashpot, which allowed the machine to operate smoothly even if the operator improperly used the handle. In 1892, Burroughs was granted a patent for the first fully functional, reliable, and practical adding machine. Large-scale production of the machines began, and his company ordered one hundred machines to be produced by the Boyer Machine Company—the same company from whom Burroughs rented shop space. The American Arithmometer Company took over production in 1895.

A man uses a Burroughs adding machine to count currency in 1956. (Getty Images)

Burroughs championed the use of fully interchangeable parts, which sped up production and made repairs easier for mechanics in the field. The demand for these types of commercial machines was spurred by a growing economy and increasingly large businesses in the late nineteenth century. The Industrial Revolution had made the mass production of these machines possible.

The Burroughs Registering Accountant, as the adding machine became known, was widely successful, particularly in banking and insurance offices. It far outsold every other calculator on the market. The machine allowed clerks to add numbers much faster and more accurately than hand calculation. A lesser-paid clerk with an adding machine could do more and better work than a better-paid clerk calculating by hand.

Because of his continual health problems, Burroughs retired in 1897. The next year, he died from tuberculosis. By the time of his death, more than one thousand of his machines had been sold. Burroughs had shown not only the technical skill to design and build his adding machine but also the skill to manufacture and market it. Though he produced and sold machines in both the United States and Great Britain, he died before he could witness the full impact of his machine. In 1904, the American Arithmometer Company moved from St. Louis to Detroit. The company changed its name to Burroughs Adding Machine Company in 1905. By 1926, more than one million machines had been sold.

IMPACT

Burroughs's machine was the first to combine the printing of totals and the printing of entries. Each function had appeared separately in patents, but not together. His was the most important and most popular of the several adding machines that came onto the market in the late nineteenth century. These early machines had to meet and beat the standards set by companies that had hired men trained as rapid “human calculators.” Once the machines were available and proved that they could perform more accurately and faster than these employees, companies began to hire less well-trained, and thus less costly, workers.

With Burroughs’s machines, companies could certainly perform calculations more quickly and keep records more current. However, the machines also allowed companies to do things they had not been able to do before because of sheer volume and the lack of cost-effectiveness. Insurance companies could create and maintain more and better charts, statistics, and records. The railroad industry could monitor its vast and growing operations. The machines also led to better bookkeeping practices with current, accurate, and more permanent records.

Burroughs was an inventor-entrepreneur who built the foundation for a strong company that far outlived him and dominated the market. The Burroughs Adding Machine Company continued to improve his design after his death, but his fundamental design remained the basis for decades. All the key mechanical innovations were patented before 1900. Burroughs’s machine was the first to include both a keyboard (for entries) and a printer (for results) and that was reliable and practical for use in business. His company was a founding member of the office equipment industry. The company, renamed the Burroughs Corporation in 1953, typified the technology, practices, and marketing of the industry. Burroughs Corporation managed to survive and even thrive despite heavy competition, and it was the only adding machine company to successfully transition into the computer age.

—*Linda Eikmeier Endersby*

THE ADDING AND LISTING MACHINE

The patent for the Burroughs Registering Accountant was granted in 1892. It became one of the most popular and well marketed of the adding machines. The success of the machine depended on not only the mechanical aspect but also the sales aspect. While the early Burroughs machines were simply encased in wooden boxes, later ones were partially encased in glass. The latter kind enabled salesmen to show the machine’s inner workings and impress potential buyers with the mechanics. Salesmen trained buyers how best to use the machine, including changes in bookkeeping practices that would take advantage of the machine’s mechanics.

The machine featured keys used to set digits and a crank that, when pulled, entered the numbers. The keyboard had nine rows of keys, one for each digit (1-9). Numbers were entered by pushing one digit in each column. A zero was represented by no keys pressed down in a column. After pressing down the keys, the operator pulled the crank forward, which caused the entry to print. Releasing the crank added the number to those already entered.

The machine printed by feeding paper from a roll between type and a printing roll (similar to a modern typewriter). An ink ribbon was interposed between the type and the paper. The type then pressed against ribbon, paper, and printing roll and produced an imprint.

The machine had several safeguards against improper operator usage. For example, it had a “locked keyboard,” which froze if an operator tried to push two keys in the same column. When a key was pressed, it stayed down so that the operator could verify the entry before pulling the handle on the side of the machine. The dashpot, or governor, was a cylinder partially filled with oil that worked up and down on a plunger. Whatever the force of the pull, the dashpot moderated it before it reached the calculating mechanism. The dashpot smoothed the machine’s operations even with improper usage by the operator.

The Burroughs Adding Machine Company (later Burroughs Corporation) produced several machines with more advanced features after William Seward Burroughs’s death. These enhancements included electrification and adding an additional adding mechanism. However, the machines were based on Burroughs’s fundamental design; all the major innovations in the adding machine field had been made before 1900.

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See also: Ted Hoff; Herman Hollerith; Jack St. Clair Kilby; John William Mauchly; Konrad Zuse.

DAVID BUSHNELL

American engineer

During the Revolutionary War, Bushnell designed and built the first attack submarine in the history of warfare. While it failed in its original objective against the British navy, it would have a significant impact on submarine technology.

Born: August 30, 1742; Saybrook, Connecticut
Died: 1824; Warrenton, Georgia
Also known as: David Bush
Primary fields: Military technology and weaponry; naval engineering
Primary invention: Bushnell's submarine

EARLY LIFE

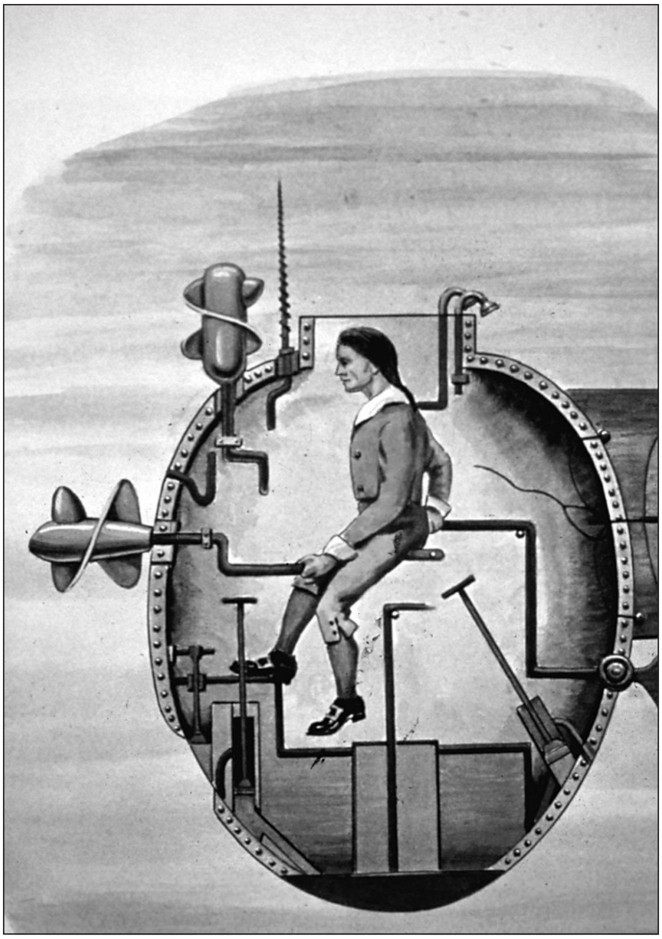
David Bushnell was born and raised on a farm near the town of Saybrook, Connecticut. His Bushnell ancestors had emigrated from England in 1639, just over a century before he was born. Between chores on his father's hardscrabble land, young Bushnell read voraciously about all kinds of gadgets and how they worked. Construction techniques also fascinated him. He hoped to deepen his understanding of science and technology at nearby Yale College (later Yale University), but lack of funds made this unattainable until he inherited a modest bequest upon his father's death.

When Bushnell finally reached the Yale campus in 1771, he was, at the age of thirty-one, by far the oldest in his class. He excelled in science and mathematics to the extent that his science professor allowed him to conduct unsupervised experiments. Bushnell had become intrigued by gunpowder for its potential military uses at a time when relations between the American colonies and the British mother country were coming under increasing strain. Finally, after many attempts, Bushnell managed to detonate underwater two pounds of gunpowder sealed in a wooden keg and detonated by a waterproof fuse. Bushnell had next to find the best means for deploying this weapon, as necessary, against the British navy.

In early 1775, Bushnell's senior year, the intensifying dispute between the colonies and England had come to flashpoint with skirmishes at Lexington and Concord in Massachusetts. Alienated by British taxation policies and by arbitrary interventions in colonial affairs, local militias were mobilized and mounted a full rebellion against their British rulers.

LIFE'S WORK

Immediately following graduation in June, 1775, Bushnell returned to the family homestead in Saybrook. Over the next year, he built and tested at his own expense a small submarine that he had designed while still at Yale. He found locally most of what he needed. Most important, he began with two large slabs cut from the trunk of an oak tree. Craftsmen then hollowed out these pieces and trimmed them to match like mirror images. They were then fitted together and sealed with tar along the seam where they came together. A band of iron was



David Bushnell's Turtle*, the first attack submarine.* (NOAA)

nailed to the seam to complete the waterproofing of the craft. The result was an oval-shaped wooden cockpit or cabin that Bushnell dubbed the *Turtle* because of its resemblance to two fused tortoise shells standing on end.

The *Turtle*'s cabin measured a little over seven feet long, six feet high, and three and a half feet wide at the middle. These dimensions allowed barely enough room for one operator, who entered through a small hatch at the top of the cabin. He sat on a wooden beam facing a whole array of devices such as valves, peddles, pumps, and shafts necessary to run the submarine. Fixed outside on the submarine's back was a wooden keg with a capacity of up to 150 pounds of gunpowder. By the summer of 1776, the *Turtle* was fully tested and ready. The American military commander George Washington had learned of Bushnell's secret project and authorized its use against the British fleet that was blockading New York harbor.

American forces defending New York City were surrounded by a veteran British army supported by warships anchored nearby. Naval cannons from the harbor regularly raked the American positions. British strategy was to take New York City and overrun the Hudson River Valley, which would split the American colonies in two. General Washington wanted the *Turtle* to disrupt the blockade of New York harbor by harassing the enemy fleet.

The *Turtle* was secretly ferried down the Connecticut River from Saybrook and poised for a strike at the British ships. However, on the eve of the attack, in August, 1775, David's brother, Ezra, fell ill with a high fever and was incapacitated for several weeks. The submarine was withdrawn, pending the training of a substitute pilot. David Bushnell himself lacked the physical strength to operate it.

A replacement named Ezra Lee was found and given accelerated training. By the evening of September 6, 1776, the *Turtle*, piloted by Lee, departed Manhattan Island and made its way slowly toward the enemy fleet. Using a pedal to work a propeller, Lee peddled the *Turtle* slowly toward its target, the HMS *Eagle*, the flagship of the fleet. The *Eagle* was a formidable frigate with its sixty-four guns pointed in all directions. To sink or damage it would have been a severe blow to British morale.

Half-submerged, the *Turtle* approached the *Eagle* while carefully observing it through a small conning tower. Lee then fully submerged by taking on water by means of a foot valve. Next, he maneuvered and stabilized the *Turtle* under the *Eagle*'s hull by using a horizontal propeller with one hand while steering with the other. A long, wood screw located outside at the top of the submarine was to drill a hole in the *Eagle*'s hull by turning into it. The 150-pound keg of gunpowder on the back of the submarine would then be drawn to the *Eagle* by an attached rope. The charge was to be fixed in the drill hole, and the rope would automatically draw the explosive container until it rested hard against the hull. An improvised clockwork timer would be set to detonate a fuse to the gunpowder once the *Turtle* was well clear of the ship.

The operation worked as planned until it came to drilling the hole. Unknown to Bushnell, the *Eagle*'s hull had a reinforcing iron bar at the point where the wood drill tried to penetrate. After several maneuvers to find vulnerable places on the hull, Ezra Lee, exhausted from his long ordeal, aborted the mission as dawn approached and headed back to shore. En route, he jettisoned the keg of gunpowder that exploded harmlessly in the bay.

Subsequently, Bushnell attempted two other attacks, neither of them successful. The failures were not due to the submarine's performance but related mostly to poor judgment and simply bad luck. Bushnell spent the rest of the war designing improved sea mines. His life after the war is something of a mystery, as he disappeared. As became clear only after his death in 1824, Bushnell had gone to rural Georgia, changed his name to David Bush, and lived out his days as a schoolteacher and physician. He never married.

IMPACT

The *Turtle* was far more than a curious fantasy of an eccentric and secretive tinkerer. Bushnell built a fully functioning submarine replete with ingenious devices and capable of delivering a lethal charge of explosives to seaborne targets. Due to Bushnell's work as an American patriot during the Revolutionary War, the "water machine" became more widely recognized as a potentially deadly new weapon of naval warfare.

Bushnell was an innovator. He was the first, for example, to successfully use pumps to fill empty ballast tanks, which allowed the submarine to submerge and resurface. This principle is still in use today, as is his idea of the screw propeller to guide the submarine. Also of significance was Bushnell's discovery of how to make waterproof powder kegs that could be detonated with a waterproof fuse either on or under the water. Here can be found the genesis of the sea mine or torpedo so well known in modern naval operations. Finally, Bushnell is credited with constructing the first documented example of a submarine actually used for combat operations. Robert Fulton's celebrated *Nautilus* submarine, completed in 1801, sported a conning tower, screw propellers for propulsion, and a procedure for detonating explosives against ships' hulls.

Frequent descriptions of Bushnell as the "father of submarine warfare" need qualification. Many of his ideas and techniques regarding the submarine came from European sources. Nonetheless, Bushnell skillfully adapted these materials to his own purposes. He was an innovator in several respects as well as a transmitter of submarine lore to future generations.

Bushnell's lack of success in his time has been described as a kind of "fertile failure" in that what he achieved would resonate. Despite the vast differences between the submarine technology of the eighteenth cen-

BUSHNELL'S SUBMARINE

David Bushnell left no drawings of his design of the *Turtle*, but many details have been reconstructed from a long letter he sent Thomas Jefferson in 1787 regarding his submarine. There are also contemporary accounts by others and a number of physical reconstructions of it over the years by naval buffs.

The *Turtle* was operated almost completely by the hands and feet of the pilot. Working the propellers alone over any distance required a strength and stamina that the rather frail Bushnell did not have. Aboard the craft itself, there were so many different tasks to be performed, sometimes simultaneously, that the pilot often needed the dexterity and concentration of a kind of one-man band.

The *Turtle* was driven through the water by two hand-cranked screw propellers. One was for vertical movement when the vessel was submerged, the other for movement forward, either on or below the surface. The forward propeller was supplemented by a rudder and tiller. Each propeller, vertical and horizontal, had a set of four blades, two on each side. They resembled the blades of a windmill and functioned like oars in the water. There might also have been a foot treadle to peddle the craft, similar to the action of a spinning wheel. The submarine had a top speed of four knots.

The second system essential to the *Turtle*'s operation involved the use of pumps, valves, and air vents. The submarine submerged by drawing water into the cabin, and it ascended by pumping the water out with two hand pumps. The amount of water let in determined how deep the craft could go—about twenty feet being the maximum. A cork barometer devised by Bushnell registered the depth at any point.

During the process of submersion, water must at times have reached almost to the knees of the pilot seated on his bench. Foot-operated valves and water pumps located at the lower front and back of the cabin were designed to drain the water out when it was time to resurface. In an emergency, a ballast of two hundred pounds of sand at the bottom of the cabin could be released. Finally, the *Turtle* had an air supply of thirty minutes maximum. It could be replenished by surfacing far enough to allow a snorkel-like device at the top of the cabin to take in air through three small sealable air vents.

Such features, along with others noted earlier, combine to make the *Turtle* a remarkable achievement and a benchmark event in the history of submarines.

tury and that of the present, with its nuclear-powered submarines and their nuclear missiles, there is still a sense in which modern submarines remain lineal descendants of the *Turtle*.

—*Donald D. Sullivan*

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See also: Robert Fulton; John Philip Holland.

NOLAN K. BUSHNELL

American electrical engineer

As the cofounder of Atari and a leading developer of some of the earliest interactive video games, Bushnell is widely considered to be the "father of the video game industry."

Born: February 5, 1943; Clearfield, Utah
Also known as: Nolan Kay Bushnell (full name)
Primary field: Electronics and electrical engineering
Primary invention: *Pong*

EARLY LIFE

Born to a Mormon family in Clearfield, Utah, Nolan Kay Bushnell had a well-rounded childhood. He enjoyed science, especially electronics, as well as debating, and sometimes used gadgetry to play practical jokes on classmates and neighbors. At age fifteen, after his father died, Bushnell took charge of some of his father's uncompleted cement construction projects. Entering the University of Utah in 1962, Bushnell participated in many school activities, and he discovered that the university possessed a computer, which was rare at that time. Although he was an undergraduate engineering student, he befriended some advanced computer science students and was allowed to work with the school's computer, one of the few computers with a monitor screen. One of their favorite pastimes was playing *Spacewar!*, considered to be the first computer game, written by Steve Russell and other scientists at the Massachusetts Institute of Technology (MIT). The game was known primarily in academic circles, especially among students who had access to the expensive computers at their respective research institutes and labs. Bushnell also learned to program in FORTRAN and other languages.

In the evenings while attending college, Bushnell worked at an amusement park not far from Salt Lake City. He made a connection between this experience of entertainment as a business and the esoteric game that he and his classmates loved so much. At this time, computers were completely beyond the reach of consumers, but Bushnell already envisioned a product that might someday bridge the gap between the multimillion-dollar lab computers at the university and the electromechanical arcade games (such as pinball) that were already a familiar part of popular culture. Bushnell, who admired the Walt Disney Company's creative use of technology, had hoped to work for the company. After graduating, however, he was hired as a research engineer by Ampex, an electronics company in California.

At Ampex, Bushnell met another engineer, Ted Dabney, who shared his interests. They decided to make a coin-operated game using parts available to them through Ampex and other sources. Their game, *Computer Space*, was essentially derived from *Spacewar!* but modified to run on dedicated hardware assemblies. Bushnell and Dabney left Ampex and sold the game to Nutting Associates, a manufacturer of coin-operated arcade game machines. Nutting went into production with *Computer Space*, and many units were constructed. However, Nutting did not present the game to an appropriately sophisticated audience; average consumers found that it was too difficult to learn. Bushnell and Dabney grew frustrated with Nutting and decided to form their own company.

LIFE'S WORK

Bushnell and Dabney initially named their company "Syzygy," using an astronomical term, but in 1972, soon after parting ways with Nutting, they registered the name Atari. In the traditional Japanese game *go*, one of Bushnell's favorite games, the expression "atari" is used when a player has his opponent's pieces surrounded. To help fund their new enterprise, which they started with only $500, Bushnell and Dabney repaired pinball machines and other arcade games, thus maintaining contact with a group of potential customers for their new technology. Having observed Nutting's experience with the marketing of *Computer Space*, Bushnell decided to make a game that would be easy enough for beginners to enjoy. One of the first new employees hired by Bushnell and Dabney was Al Alcorn, another engineer who had worked at Ampex. To give him experience in designing dedicated transistor-to-transistor logic devices, Bushnell asked Alcorn to make a simple ball-and-paddle game. Although the assignment was originally intended as a kind of exercise, Alcorn took the assignment very seriously. As the new device took shape, Bushnell recognized its potential, and the team added additional features. The resulting product was named *Pong*, and it became an immediate success. Bushnell decided that Atari would do the manufacturing as well as the design.

To meet the demand for *Pong*, Bushnell expanded Atari's facilities. Because the game's logic structure was revealed visually by the physical connections between its components, many competitors created their own versions. Although the market was soon flooded with imitations, Atari created variations of *Pong* and eventually created new games based on similar technologies. *Space Race*, the company's next game, was released in 1973 and quickly copied by Midway. The frenzied accelerating corporate competition, with innovation followed by imitation, resembled the accelerating pace of the games themselves. As Atari expanded, Bushnell and his young employees maintained a casual atmosphere that rejected the formality of other companies. The most well-known former Atari alumni are Steve Jobs and Steve Wozniak, who struck out on their own to form Apple Computer after having first invited Atari to invest in their idea of marketing personal computers.

Nolan K. Bushnell. (AP/Wide World Photos)

Because distributors in the coin-operated games business tended to rely on individual manufacturers, Atari's many competitors were able to grab segments of the market. As a way of working around this, Bushnell created a second highly successful company, Kee Games, which sold variations of Atari's products under different names. As microprocessors increased in power and lowered in cost, it became more possible to use programmed rather than hard-wired game logic. In 1975, Sears marketed Atari's home console version of *Pong* using a single chip that contained all of the logic required. Atari was purchased by Warner Communications in 1976, and Bushnell, who stayed with the company for some time after that, made millions of dollars of profit.

Bushnell's next important venture was Chuck E. Cheese, which he had developed for Warner while still at Atari. Chuck E. Cheese focused on family entertainment by combining pizza and soft drink service with video game arcades and entertainment by animatronic characters. He purchased the company from Warner in 1977 and left in 1984. By this time, Bushnell was involved in multiple projects and activities, including investments with the Catalyst Technologies Venture Capital Group, which he had founded in 1981 and which supported many new initiatives in game technology, robotic toys, and entertainment. Another of his companies is uWink (founded in 2000), which also combines dining and gaming experiences. Bushnell has appeared on documentary programs, and in 2005 he appeared as a judge in several episodes of the reality show series *Made in the USA*.

IMPACT

Atari ultimately had difficulties in maintaining its economic momentum, but Bushnell's combination of technical knowledge, creative imagination, and entrepreneurial risk-taking continued in the industry that he had helped to establish. As a direct result of the activities of Bushnell (along with his many competitors and imitators), both coin-operated video game stations and in-home game devices connected to television sets became an important and familiar part of popular culture throughout the world. Within the entertainment industry, his use of electronics to control full-size characters in restaurant settings extended Disney's theme park animatronics concepts into new environments.

PONG

Pong was the first commercial video game to achieve widespread popularity. There were two slightly earlier but less successful inventions that introduced certain features brought together in *Pong*. The first was Nolan K. Bushnell and Ted Dabney's *Computer Space*, released by Nutting Associates in 1971. *Computer Space* was a coin-operated self-contained video game that used hard-wired discrete logic gates made from inexpensive components (rather than a program running on a central processing unit) to achieve a complex level of interactivity. The second preceding invention was the first home video game console: the Odyssey Home Entertainment System, created by Ralph Baer and released by Magnovox in 1972. The Odyssey also used inexpensive components, transistors and diodes, in a system connected to a television set. The Odyssey would play several different variations of a simple paddle game, with cartridges inserted to activate the games.

Meanwhile, Bushnell and his new engineer Al Alcorn, who had left Nutting, continued to perfect transistor-to-transistor circuits for their coin-operated games. Later in 1972, Atari released *Pong*, after testing a prototype in a local bar. Although it was essentially a stand-alone two-person paddle game simulating table tennis, *Pong* included several innovative features that distinguished it from *Computer Space* and the Odyssey. Like *Computer Space*, there were separate circuits for the various functions of the game. In this case, there were circuits to keep track of the positions of the paddles and the ball (by counting scan lines), circuits to handle paddle input from the knobs, a digital counter to keep score, and circuits to change voltages that generated the patterns of light and darkness between each scan cycle on the TV screen. As the game progressed, the speed of the ball would increase, resulting in an increase in the level of challenge. Each of the paddles was divided into areas that would affect the angle of deflection when the ball was contacted, adding an exciting level of realism. As another innovative touch, some of the waves created by the voltage changes in the device were amplified and sent to a speaker to create the characteristic impact sound selected by Bushnell. The combination of increasing speed, changes in the ball's deflection angle, scorekeeping, and sound created an unprecedented level of interactivity.

Ironically, it was a mechanical feature that caused the first problems with the new invention. When the prototype was being tested in a consumer setting, Alcorn received a call to let him know that the machine had stopped working. When he investigated, he found that the machine's very popularity had caused the malfunction. Like the pinball machines that preceded it, *Pong* had a coin collector, which had overflowed. Aside from its technical innovations and efficient design, the psychological dimension of user engagement ushered in a new art form. *Pong* exemplified Bushnell's game design philosophy, which dictates that a game should be easy to learn but difficult to master.

Bushnell also played a role in an ongoing argument over the future of technology. Alan Mathison Turing, a pioneer in the earliest days of computing, had envisioned a flexible approach in which a single computer would be programmed to do many divergent tasks. In some ways, by creating dedicated hardware for gaming, Bushnell and his associates challenged the multiple-function approach envisioned by Turing. Atari's famous rejection of Steve Jobs's offer to have the company invest in the development of personal computers is another example of Bushnell's approach. With the passage of time, personal computers did become important as gaming platforms, but dedicated gaming hardware also continued to develop and to play a large role in consumer culture as the home console market expanded and diversified.

—*John E. Myers*

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See also: Bill Gates; Steve Jobs; Ken Olsen; Alan Mathison Turing; Steve Wozniak.

CAI LUN

Chinese court official

Cai Lun is credited with inventing the process of papermaking by suspending mashed fibers in water, screening out the water, and drying and polishing the remaining sheets. This basic process remains the same today.

Born: c. 50 C.E.; Guiyang (now Leiyang, Hunan Province), China
Died: c. 121 C.E.; China
Also known as: Jingzhong; Ts'ai Lun (Wade-Giles)
Primary field: Manufacturing
Primary invention: Paper and papermaking

EARLY LIFE

Little is known about the early life of Cai Lun (si loon) beyond the date and place of his birth. From his later career at the Chinese imperial court, however, it is possible to infer some further elements of his childhood and youth. Cai Lun lived during the Eastern, or Later, Han Dynasty. This was the first dynasty in which China was united in culture and government under a far-reaching imperial establishment. To manage such an extensive empire, the court needed a large number of competent administrators. Chinese court officials were always on the lookout for able young men to join their ranks. Of prime importance to ambitious young men were intelligence and a good education. More than nine thousand characters existed in the written Chinese language at this time, and many years of study were needed for proficiency. It is likely that Cai Lun came from a comfortably situated family, if not a wealthy one, and that he attended either a government or a private school. When he entered imperial service at about the age of twenty-five, he would have already gone through years of study and must have ranked well in his examinations.

LIFE'S WORK

Cai Lun began his service as court eunuch about 75 C.E. His initial duties are not known, but they probably included a component of secretarial work. Most of his assignments would have been administrative rather than purely scientific. However, he seems to have been genuinely interested in the pursuit of knowledge. He was known as a serious and careful man who in his leisure hours would seclude himself in his quarters to study. Like any political center, the Han imperial court was rife with factions and with individuals jockeying for power. To survive and advance in this setting as he did, Cai Lun also had to navigate the dangers of imperial politics and make powerful friends.

His abilities were recognized by a series of promotions. By 97, he was appointed inspector of works. In this post, he oversaw the production and improvement of swords, weapons, and other devices. Perhaps his interest in manufacturing processes was already evident.

His experiments with papermaking seem to have been spurred both by his own curiosity and by necessity. The Eastern Han Dynasty was the heir of a long tradition of written language. The earliest traces of writing found in China were inscribed on a variety of natural materials: bone, stone, clay, and metal. These were substances especially suited for recording messages aimed at future generations as well as the writer's contemporaries. However, the Han Dynasty faced the complex problem of governing a population of some sixty million people. Just keeping up with its ordinary business required much written communication. Most of such writing was done either on sheets of silk or on wooden or bamboo strips. The writing implement used was a small brush. Learning to wield it gracefully was an integral part of learning to write the ideographic characters.

Both silk and wood had major drawbacks as writing surfaces. Silk, which was used for most official documents, was expensive and fragile. The brushed ink strokes also bled through it, so only one side of the silk sheets could be used. Bamboo and wooden strips were more substantial, but heavy and bulky. For longer texts, books were created by binding or strapping together a series of strips so each could be unfolded as the reader came to the bottom of the previous strip. Wood strips were used for the majority of ordinary messages.

Clearly there was a need for another medium for the written word. It must be noted that Chinese did have a word for paper, *chi*, before Cai Lun's invention of papermaking. In 102, the imperial consort Teng, one of Cai Lun's sponsors, requested that samples of *chi* be sent to her from various regions. *Chi* is also mentioned even earlier. Archaeologists have determined that *chi* appears to have referred to coarse pieces of treated hemp fibers, although thin mulberry bark is also a possibility. The use of these substances was no doubt known to Cai Lun when he began his experiments.

It is not known how long it took him to work out the process, how many assistants he had, or whether he did the work at court or at his home in Leiyang, where a stone mortar was exhibited in later years as the one he used in papermaking. Also, there is no "recipe" for the proportions of the different fibrous materials that made up the finished product. The basic facts of his invention were recorded by court historians. Taking a mixture of materials—including hemp ends, tree bark, and scraps of fish net—he perhaps presoftened them, then crushed them into tiny fragments and suspended the mix in water. This wet pulp was then spread evenly on a screen of cloth or bamboo and dried in the sun. Once totally dry, it emerged as a new substance, paper, which could be peeled off the screen and polished to a relatively smooth surface with a stone.

Cai Lun presented a report on his papermaking process to Emperor He in 105 It was immediately recognized as an important advance, and Cai Lun won imperial commendation for his work. Even though some of the materials and steps of the process were already in use, he had brought them together to create a new product with superior qualities and a huge number of possible uses.

Even so, his invention did not revolutionize written communication overnight. Existing materials continued to be used for many books and messages. In fact, when an official version of the classical texts was commissioned by the emperor in 175, it was engraved on stone tablets. (This medium, however, made it possible for scholars to take rubbings of the engraved works on paper, for their own use.) Paper's use for written messages seems to have begun soon after Cai Lun's disclosure of the papermaking process, but paper did not replace other materials in China for many years. The earliest authenticated example of paper containing writing was found in 1942 at the ruins of a frontier watchtower that was manned during the Han era. Members of the Chinese Academy who discovered it dated it to between 109 and 110, just before the watchtower was destroyed. The paper, made of vegetable fibers, contains some twenty characters. Its existence suggests that Cai Lun's techniques spread fairly quickly. Other practical uses for paper, including serving as a wrapping material, toilet tissue, and even as clothing, were also adopted rapidly in China.

Cai Lun himself continued his career as a courtier and imperial administrator. In 114, he received the title of marquis; this was a select status outranked only by certain kinsmen of the emperor. Among other privileges, it entitled him to the income from three hundred dwellings. He was also appointed a chief, or chamberlain, of the palace. In 117, he was named to head a project to reconcile differing versions of the "books of history." His papermaking endeavor seems to have been picked up and carried on by others. His apprentice Zo Po added improvements to the process. One source credits Cai Lun with setting up a paper factory in Turkestan. It does seem likely that, once familiar with this new product, the Han authorities would encourage its large-scale production.

Unfortunately, the palace intrigue that helped in Cai Lun's rise also brought about his downfall. He was strongly supported by Dowager Empress Teng, the same

PAPER AND PAPERMAKING

The basic components of paper are simple. Starting with organic materials of vegetable origin, small strips or pieces are sometimes pretreated to soften them, then are put through a process to disrupt the natural structure and rebond the fibers through a process similar to felting. When this process is done by hand, after water is added the pulp is beaten by a stone, a wooden mallet, or another implement. Sometimes animal-powered mallets are used. Mechanization allowed larger batches to be processed at once, with devices pulverizing the material without using direct human effort. The Hollander beater, for example, was first devised in the Netherlands in the seventeenth century. It used wind power to turn heavy cylinders with multiple teeth over and over in a huge tub, mashing wet fibers into pulp.

After the mixture is the right consistency, it is spread or poured to cover a flat surface evenly. This can be as small as Cai Lun's hand screens or, as in today's factories, the size of a small playing field. The next step, extracting the liquid, in early modern times was largely accomplished by pressing the mixture down with heavy wooden or metal presses. Used repeatedly, they would remove most of the pulp's 99 percent component of water. The resulting sheets were then hung or spread in a drying loft to air-dry completely. With modern papermaking machines, heavy cylinders serve as presses and, once the paper comes off these rollers, it is ready for processing into the designated final product.

Contemporary paper mills are automated, so their controls can be adjusted to produce papers of varying thickness, texture, sheet size, absorbency, and other traits. Chemical treatments are usually added during the process. An immense variety of paper products with diverse qualities and uses now roll out of paper mills over the world. Cai Lun's invention has proved uniquely essential to modern civilization.

woman who had taken an interest in his papermaking venture. After her death, he was implicated in a threat to her rival, the new empress. Rather than being executed, he was allowed to bathe, dress in his finest formal robes, and take poison. He died in 121.

IMPACT

The importance of Cai Lun's invention can hardly be overstated. Paper serves many purposes. For most of these, any substitute substances have significant drawbacks. Paper is reasonably durable, light, biodegradable, absorbent, and capable of being made from a variety of natural vegetation. It can be manufactured so cheaply that almost everyone can use it. Unlike electronic communications methods, records kept on paper can be made, retrieved, and read or viewed without any intervening device. Under the right conditions, they can be kept intact for long periods of time without being made inaccessible by newer technology. A world without paper is now almost impossible to imagine. It remains of huge importance for conveying written and printed information, but it also forms part of the everyday environment in many other ways.

The technology and use of paper spread rapidly through China and the rest of East Asia in the first few centuries after Cai Lun reported his invention. Samarqand became a paper-manufacturing town following a battle fought there when two Chinese papermakers taken prisoner offered knowledge of their craft in exchange for their freedom. Papermaking knowledge spread along the Silk Road and met with many innovations in an Arab world newly flourishing with commerce and conquest. Paper was first introduced into Europe in Spain, by the Moors, and Italian papermakers were also operating by the end of the thirteenth century. The craft spread slowly to the rest of Europe, because it was viewed with some suspicion during the transition from medieval to modern times. However, paper was so integrally important to the spread of the printed word, and to the needs of a society in which literacy and record keeping were increasingly important, that by the sixteenth century it was being produced and used in most European countries. Today, it is hard to find a corner of the world where paper is unknown.

—*Emily Alward*

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See also: Johann Gutenberg.

ROBERT CAILLIAU

Belgian electrical engineer

In collaboration with Tim Berners-Lee, Cailliau invented the World Wide Web, which revolutionized communication and information sharing throughout the world. First developed as an essential tool for the scientific community, the World Wide Web soon became a technology available to everyone.

Born: January 26, 1947; Tongeren, Belgium
Primary field: Computer science
Primary invention: World Wide Web development

EARLY LIFE

Robert Cailliau (roh-BEHR ki-JIOH) was born on January 26, 1947, in Tongeren, Belgium, located north-northwest of Liège. Although his name appears to be French, he comes from a Flemish family that traces its residency in Flanders back to 1602. Cailliau grew up speaking a Dutch dialect. In 1958, his family moved to Antwerp, and he attended the Rijks Atheneum school. After graduating from secondary school, he attended Ghent University, where he had his first experience working with human-machine interfaces in a lab class for mechanical engineering. In 1969, he graduated from Ghent University with a degree in electrical and mechanical engineering. He then worked at the university until he attended the University of Michigan to further his studies. In 1971, he completed a master of science degree at the university. His area of specialization was computer, information, and control engineering, with a concentration in operating systems and programming languages. In 1972, he returned to Ghent University. The following year, he did his military service in a post at the Belgian Royal Military Academy. While at the academy, he began writing FORTRAN programs, in which he simulated troop movements.

LIFE'S WORK

In 1974, Cailliau accepted a position at the European Council for Nuclear Research (later renamed the European Organization for Nuclear Research), known as CERN, in Geneva, Switzerland. Cailliau held positions in four different departments while at CERN. His first position was as a member of the team working on the control system of the Proton Synchrotron accelerator. During this time, he met Tim Berners-Lee, who was working for CERN as a contract programmer. From 1986 to 1989, Cailliau was head of Office Computing Systems at CERN. He was chosen for this post because of a text-processing system that he had written with a friend. During this time, he began considering the creation of a hypertext system that would connect all of the documentation over the CERN network.

In 1989, CERN was restructured, and this change enabled Cailliau to begin seriously working on a hypertext system. For some time, Cailliau worked on the idea by himself, as no one else at CERN was really interested in it. However, Berners-Lee was already working on similar ideas. The two men collaborated and developed a project that Berners-Lee had begun at an earlier date, “Information Management: A Proposal,” which was renamed “WorldWideWeb.” They received approval from CERN to spend a year developing the project. Working under Mike Sendall, Cailliau and Berners-Lee developed a network hypertext system. By the end of 1990, their system was introduced as the World Wide Web. It quickly won the support of physicists, and on April 30, 1993, CERN, at the insistence of Cailliau, put the World Wide Web in the public domain.

In 1993, Cailliau joined a group from Fraunhofer Gesellschaft in working on a Web-based project under the auspices of the European Commission. He also began planning the first International WWW Conference, which took place in May, 1994, at CERN. The conference was well attended, and its success resulted in the formation of the International World Wide Web Conference Committee, which organized annual conferences. Cailliau served on the committee from 1994 to 2004.

In 1994, in conjunction with the European Commission, Cailliau started the Web for Schools program, which was the initial step to establishing the Web as a resource to be used in educational programs in the European Union. He was also instrumental in setting up the World Wide Web Consortium (W3C), which oversees the standards of the World Wide Web. Cailliau transferred the Web technologies from CERN to the consortium. His work at CERN was involved with the CERN intranet services.

Cailliau then moved to another division of CERN. During the time he spent trying to convince various individuals of the value of the Web, he became keenly aware of the difficulty of introducing new ideas to people. In 2000, he published *How the Web Was Born: The Story of the World Wide Web* with James Gillies of CERN.

THE WORLD WIDE WEB

The concept of the World Wide Web (WWW) was the result of the need of scientists worldwide to be able to communicate quickly and easily with each other and to access information. The European Organization for Nuclear Research (CERN) was the site at which the research and development of the concept began. The CERN laboratories served as a focal point for scientists working in universities and national laboratories throughout the world. Many of these scientists spent some time actually working at CERN, but most of their work was done in their home countries; therefore, they needed to contact each other quickly from wherever they happened to be.

In 1989, the first proposal for the World Wide Web was presented by Tim Berners-Lee, a computer scientist who had joined CERN as an independent contractor in 1980. At that time, he developed a prototype system based on the concept of hypertext to make it easier for research scientists to share and update information. The system was called Enquire. His 1989 proposal used many of the ideas he had utilized in Enquire. Robert Cailliau, also a CERN scientist, was experimenting with this same idea of establishing a network for scientists who had worked at CERN to communicate easily once they returned home and to be able to access what Cailliau called an "automatic library." Cailliau and Berners-Lee began working together and in May of 1990 presented a refined version of the 1989 proposal. The proposal was approved by their manager, Mike Sendall, and they began developing the World Wide Web. By the end of the year, they had written prototype software for a basic system. Berners-Lee built the first Web browser and editor, which he developed on the NEXTSTEP operating system, and the first Web server, called "httpd" (hypertext transfer protocol daemon). All of the first Web servers were in European physics laboratories, making the Web available to a limited number of users.

In 1991, the Web became accessible to a large number of research and university laboratories in Europe. Then, in December, 1991, the first U.S. Web server came online at the Stanford Linear Accelerator Center in California. In 1993, the development of reliable, user-friendly browsers for personal computer (PC) and Macintosh computers provided the impetus necessary for a significant increase in Web servers and users. On April 30, 1993, CERN placed the World Wide Web in the public domain, and in 1994 the first International World Wide Web Conference took place. CERN determined that it was no longer the proper base for Web development and proposed that an international consortium be established in collaboration with Massachusetts Institute of Technology (MIT). The French National Institute for Research in Computer Science and Controls took over for CERN. In January, 1995, the World Wide Web Consortium (W3C) was founded to oversee and advance the development of the Web. Berners-Lee left CERN at the end of 1994 to work on the consortium at MIT.

Cailliau then became head of CERN's External Communications division. He remained in this position until his early retirement in 2005.

After retiring, Cailliau began sharing his knowledge as a speaker at conferences. He has also devoted his time to teaching programming to children and adolescents with severe learning and/or social disabilities through the Internet-based educational charity Not School. He uses Revolution, a programming language that started as MetaCard, to teach his students. Cailliau has also been working on a major project that deals with a Hyperbook-generating program he calls iAlbum.

Cailliau has received numerous awards and recognitions for his scientific work. In 1995, he was chosen as the recipient of the ACM Software System Award along with Tim Berners-Lee. In 1999, he received the Plantin Prize awarded by Antwerp and was given an honorary doctorate by Southern Cross University in Australia. In 2000, he received an honorary doctorate from Ghent University. In 2001, once again with Berners-Lee, he was the recipient of the Médaille Genève Reconnaissante. In 2004, King Albert II of Belgium awarded him the Commander in the Order of King Leopold. Cailliau was given honorary citizenship in the city of Tongeren in 2006.

IMPACT

Cailliau played an important role in making the concept of the World Wide Web a reality. Working with Berners-Lee, he convinced CERN to back the project. Then, in 1993, he was instrumental in persuading CERN to place the World Wide Web in the public domain. His efforts brought about the International World Wide Web Conference series, an annual event bringing together researchers and computer scientists. He has been one of the major proponents for using the Web as an educational tool both in the schools, with programs such as Web for Schools, and totally online, such as Not School.

—*Shawncey Webb*

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See also: Tim Berners-Lee; Vinton Gray Cerf; Philip Emeagwali; Bill Gates; Bob Kahn; Robert Metcalfe; Larry Page.

JOHN CAMPBELL

Scottish naval officer

Campbell, an exemplary British naval officer of the eighteenth century, was critical in the development of the nautical sextant, an instrument that precisely measures angular distance of celestial objects from the horizon to chart location. Since its inception, the sextant has become essential for marine navigation.

Born: c. 1720; Kirkbean, Kircudbrightshire, Scotland
Died: December 16, 1790; London, England
Primary fields: Maritime technology; navigation
Primary invention: Nautical sextant

EARLY LIFE

John Campbell was born in the parish of Kirkbean in Kircudbrightshire, Scotland, around the year 1720. His father, also named John, was the minister of the local parish. Campbell began his naval career as an apprentice on a coasting vessel. Shortly thereafter, he joined the British Royal Navy and in 1740 became midshipman on the *Centurion*. The *Centurion* sailed in Commodore George Anson's fleet in its famous circumnavigation around the globe; Anson would advance Campbell's career at every opportunity. With outstanding sailing skills and devotion to the navy, Campbell quickly rose through the ranks. In 1743, he was appointed master and in 1745 lieutenant. In 1749, he was promoted to post captain of the *Bellona*, a frigate. Among seamen, Campbell would earn an almost unrivaled reputation as an astronomer and navigator, two arts linked in maritime journeys. He was also commended for his abilities as a naval officer.

LIFE'S WORK

Campbell's first recorded efforts at advancing the art of navigation by the stars—as mariners had been doing since the first oceanic journeys—were in relation to the octant. About 1747, he was the first person known to employ the octant designed by John Hadley to measure at sea the angle of distance between the Moon and the stars. Given his success, Campbell was asked in 1752 by the Board of Longitude (created in 1714 to solve the problem of finding longitude at sea) to test the new lunar tables and circular repeating instrument of German geometer and astronomer Tobias Mayer. Appointed the captain of the *Essex* gunboat in 1757, Campbell successfully carried out the experiment. However, he found Mayer's circular repeating instrument cumbersome in comparison with the wooden Hadley octant. Campbell's trials led him to suggest important modifications to the octant. He suggested that the instrument's arc be extended from 45° to 60° so that its range of measurement would be increased from angles up to 90° to angles up to 120°. He also suggested that, to increase the stability of the navigational instrument, its frame be changed from wood to brass. Finally, he made better use of the telescopic sights.

When the renowned instrument maker John Bird employed Campbell's suggestions in 1759 to make a measuring instrument of eight inches radius with a brass frame, the first marine sextant had come into existence. The sextant built from Campbell's suggestions was such a success that it became the standard maritime charting instrument for the next two centuries. It was particularly successful in determining longitude by observing lunar distances according to methods developed by Royal Astronomer Nevil Maskelyne. The sextant allows for precise locating of one's position at sea by measuring the altitudes of the Moon, Sun, planets, or stars above the visible oceanic horizon. Technically, it works by measuring the angle between two points by bringing the direct image from one point and a double-reflected image from another point into alignment. The angular reading is taken from the sextant's arc to measure both longitude and latitude. Yet for all of its precision and working parts, Campbell's sextant was only one-third the weight of the Mayer circle. Edward Troughton improved Campbell's sextant in 1788 by patenting a lightweight double frame. Unlike some of its predecessors, the sextant could be used both day and night. The shades allowed for dimming bright objects; calculation of the stars could be made even when the horizon was not visible.

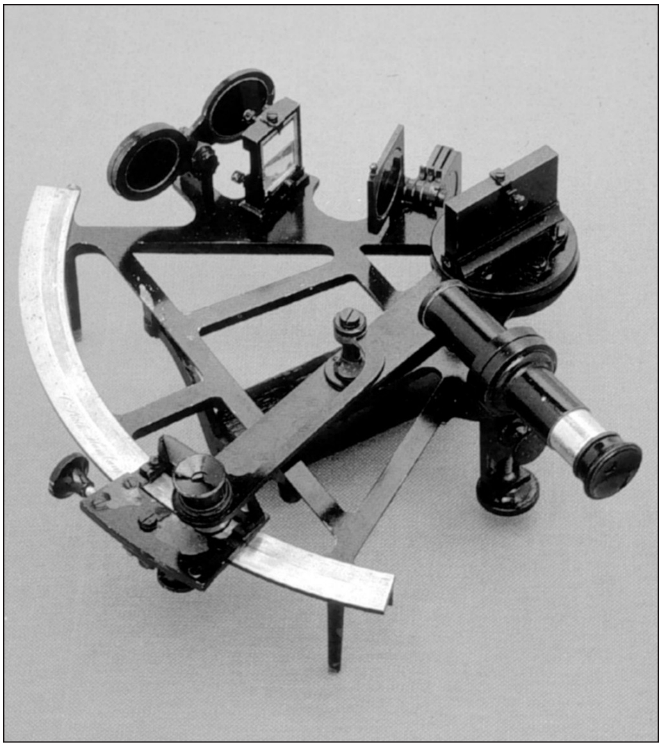
The ships that Campbell commanded took part in several victorious sea battles. In November, 1759, Campbell and his lifelong mentor, Admiral George Anson, personally informed the king of the British victory at Quiberon Bay. On May 24, 1764, Campbell became a member of the learned Royal Society. As a Royal Society fellow, he carried out a sea trial of John Harrison's longitude marine clock on the *Dorsetshire*, which Campbell had commanded since 1760. Harrison's "chronometer" would eventually win the prize of £20,000 offered by the Board of Longitude. In March, 1765, Campbell visited the Royal Observatory in Greenwich, England. On November 19, 1767, he was appointed a member of the Royal Society's Transit Committee to arrange for global measurements of the June 3, 1769, transit of Venus.

At a Royal Society council meeting on December 3, 1767, it was suggested that Campbell, as a "lover of astronomy," captain a ship to the South Pacific for this purpose. He apparently declined, but at a council meeting on May 5, 1768, he suggested that Captain James Cook lead the expedition. The Admiralty had already instructed the Navy Board to outfit a ship for this venture, and on August 25, 1768, Captain Cook launched his famous voyage of discovery on the *Endeavour*. (Cook named a New Zealand cape for Campbell.) Campbell was also instrumental in the rise of William Bligh, who captained his first ships in Campbell's service. Campbell commanded several additional ships until January 23, 1778, when he was promoted to vice admiral. Two months later, he became first captain of the *Victory*.

In 1782, Campbell was appointed governor and commander in chief of the English colony on Newfoundland. By all accounts, he was an enlightened and productive governor. For example, he allowed religious freedom for all of Newfoundland's inhabitants. As a result, Newfoundland's Catholic bishop authorized the construction of a chapel. Campbell also established a public wharf and storehouses for the benefit of the Newfoundland residents. As governor, he continued his navigational trials, testing the chronometer of Thomas Mudge and ascertaining the longitude of Newfoundland. Campbell retired to England in 1786. He died at his house at Charles Street, Berkeley Square, London, four years later, perhaps survived by his wife.

IMPACT

Campbell made a lasting impact on navigational history with the development of the nautical sextant. It is perhaps excessive to call Campbell the in-



A sextant. (NOAA)

ventor of the sextant, as it is an instrument that evolved from its eighteenth century predecessors, most notably the quadrant and the octant. In addition, it was the great skill of English crafts firms and instrument makers—such as John Bird, who constructed the sextant from Campbell's suggestions—that made progress in marine instrumentation possible. Nevertheless, Campbell's improvements to the arc scale, frame, and sights of the octant were decisive in creating the essential navigational instrument for the modern sailor—the nautical sextant.

Campbell's insight followed from the two central marks of his career—his outstanding seamanship and his expertise in astronomical navigation. Throughout his career as sailor, captain, admiral, and governor, Campbell was noted for courage, integrity, and seamanship. His astronomical ability was such that the Board of Longitude repeatedly asked him to carry out trials at sea of the latest navigational instruments. The success of such experiments were critical to the Royal Navy as it was becoming a worldwide power. In turn, Campbell was able to use the results of his sea trials and his acquired experience to develop the sextant.

The British navy of the eighteenth century was the most powerful force at sea that the world had ever seen and the critical military branch of the British Empire spanning the globe. Certainly, many factors contributed to the success of the Royal Navy—the stable political institutions of Great Britain, its advances in industry and technology, successful scientific and bureaucratic institutions such as the Board of Longitude, the fine workmanship of shipbuilders and instrument makers—but not to be underestimated are the contributions of sea captains like Campbell who combined outstanding seamanship, devotion to service, astronomical knowledge, and scientific curiosity. The result was the invention of the nautical sextant.

Although invaluable to ocean travel, the sextant has been used in other fields. The sounding sextant is constructed for horizontal rather than vertical use and is used in hydrographic surveys. The surveyor's sextant is used on land for horizontal angular measurements. Box sextants are also used by surveyors.

—*Howard Bromberg*

THE SEXTANT

The sextant was the chief navigational tool for maritime transport for two centuries. It is an ingenious device for finding one's position on the sea by measuring the angle of a celestial body above a horizontal line of reference. The measurement of the angle and the elapsed time is used to chart a position line on a nautical chart. For the entire history of ocean travel, mariners have needed an accurate method to locate their positions by the only constant observable to them—the stars. With advances in maritime science, navigators began using some kind of astronomical instrument to map their positions according to the Sun, Moon, planets, and stars. The sextant developed from and improved upon these astronomical instruments.

Over the course of history, marine navigators have variously used latitude hooks, kamals, astrolabes, balestillas, cross-staffs, back-staffs, nocturnals, and quadrants for this purpose. Similar to the principles that led him to invent the reflecting telescope, Sir Isaac Newton had already suggested the idea of making use of moving mirrors as reflecting instruments. Newton's idea of doubly reflecting mirrors allows for subtracting the motion of the sextant from the reflection. The eighteenth century octant was the direct forerunner of the sextant. John Hadley and Thomas Godfrey had independently developed effective marine octants around 1731, both employing double-reflecting mirrors. John Campbell's modifications transformed the octant into the most successful ocular instrument in the history of marine navigation—the sextant.

The name "sextant" is derived from the Latin *sextus*, or sixth part of a circle. Prototypes of the instrument had been used by astronomers since the sixteenth century. The famous astronomer and compiler of celestial data Tycho Brahe had developed a forerunner of the sextant, but it was with Campbell that the nautical sextant took final shape. The sextant enables sailors to calculate their longitudinal and latitudinal position based on precise measurements of the angles of celestial objects. The sextant also makes use of the innovation of the double-reflecting mirrors. The sextant combines two mirrors or prisms, a telescopic sighting tube, an arc scale, and a shaded micrometer. The observer adjusts the components to measure the angle of a celestial object—the Moon, Sun, planet, or star—compared to the horizon. With the measurement calculated by a time frame, it is possible to achieve highly accurate readings of the latitude and longitude based on the perceived movement of the celestial object. The sextant was often used with the chronometer, a precision time-measuring device. Compared with its predecessors, the sextant was sturdy, lightweight, portable, and extremely accurate, even on a moving ship. With its invention, mariners had the ideal tool for charting their positions. Even with the increasing use of electronic locating devices, the sextant remains an important navigational tool.

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See also: Martha J. Coston; Nils Gustaf Dalén; John Harrison; Jesse Ramsden; Elmer Ambrose Sperry.

MARVIN CAMRAS

American electrical engineer

Camras invented a magnetic tape recording process widely used in electronic media, including music and motion-picture sound recording, audio and videocassettes, floppy disks, and credit card magnetic strips.

Born: January 1, 1916; Chicago, Illinois
Died: June 23, 1995; Evanston, Illinois
Primary field: Electronics and electrical engineering
Primary invention: Magnetic tape recording

EARLY LIFE

Marvin Camras was born in Chicago, Illinois, on New Year's Day, 1916. From early childhood, he was fascinated by technology. At the age of four, he built a flashlight, and he later designed a working telephone so he could talk with his cousin William. After high school, Camras attended the Armour Institute of Technology (now the Illinois Institute of Technology, or IIT), where he studied electrical engineering. At that time, his cousin was hoping for a career in opera.

Camras searched for a way to record his cousin's voice. Drawing upon the work of Danish inventor Valdemar Poulsen (1869-1942), whose telegraphone was an early device for recording sounds magnetically, Camras tried using magnetized piano wire to record his cousin's singing. In early attempts, the wire twisted during playback, distorting the sound. Camras kept working on his invention and eventually found a solution. He designed a magnetic recording head that would surround the wire but not actually touch it. The results were impressive, at least in terms of recording quality. When Camras demonstrated the wire recorder for his professors at the Armour Institute of Technology, they were so impressed with the clarity of the sound reproduction that they offered Camras a position at the Armour Research Foundation. William, apparently, was less impressed: After hearing the playback of his voice, he gave up his plans for a singing career.

LIFE'S WORK

Marvin Camras received his bachelor of science degree from the Armour Institute of Technology in 1940, during the final years of the Great Depression. Unlike many new graduates of that time, he was fortunate to have a job waiting for him upon graduation. Camras's professors encouraged him to keep working on his wire recording techniques at the Armour Research Foundation, which in 1940 merged with the Lewis Institute to become the Illinois Institute of Technology, while earning his master's degree. Camras completed his M.S. in 1942.

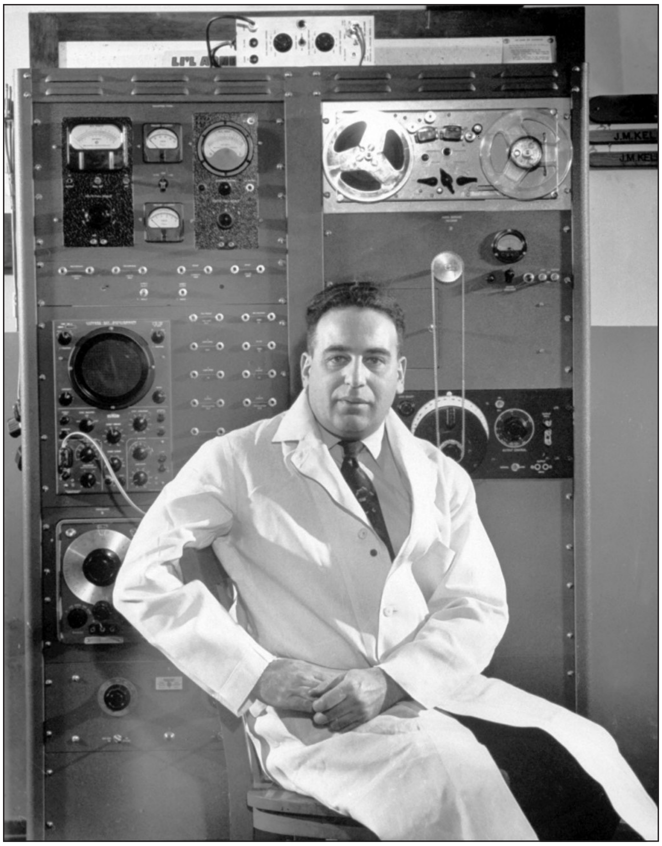
In December, 1941, Camras submitted his first patent for a "Method and Means of Magnetic Recording." It was approved in 1944. By this time, the United States had entered World War II, and Camras's work attracted the attention of the military. An article published in *Time* magazine in 1943 discussed the potential wartime benefits of Camras's "highly portable little gadget," a wire recorder approximately the size of a typewriter and weighing ten pounds. Far less bulky than earlier recording devices, the magnetic wire sound recorder Camras developed was seen as a way for newscasters to record live broadcasts from the scene of battle. The article noted that Camras, described as a "stocky, shy 27-year-old," would receive a 25 percent royalty for each recorder sold.

During World War II, Camras's wire recorders were used by the armed forces for training and intelligence purposes. The Navy used his recorder during submarine pilot training to simulate depth-charge attacks. The Army also used Camras's "Model 50" recorder for a special military disinformation program kept secret until after the war. To divert the attention of enemy forces, battle sounds were recorded and amplified, then played in locations where the D-Day invasion was not going to take place.

After the war, Camras continued working on recording techniques but switched his medium from wire to a thin, flexible yet durable tape. After experimenting with many different methods to magnetize the tape, he developed a ferric oxide "paint." This coating, whose particles would align uniformly when magnetized, created an ideal recording surface. This innovation proved to be an enormous commercial success, making "tapes" of one sort or another (audio, video, even computer) a nearly ubiquitous household item. In his *Magnetic Recording Handbook* (1988), Camras describes the introduction of a home tape recorder in 1946; as postwar prosperity increased the market for consumer goods, such products and their accessories became a multimillion-dollar industry.

Continuing to innovate, in 1949 Camras invented high-frequency bias recording, a method of using high-frequency sounds to sensitize magnetic tapes, allowing for a clear, almost distortion-free reproduction of sound. Camras describes the complex process in depth in his *Magnetic Recording Handbook*. Some of his other inventions included patents in methods of stereo tape recording, multitrack recording, motion-picture soundtrack recording, and an early prototype (1950) of a videotape recorder. In all, Camras patented more than five hundred inventions, largely in the field of electronics. Among the corporations that licensed his patents were General Electric, Minnesota Mining and Manufacturing (3M), and Eastman Kodak.

Despite his many successful inventions, Camras never attained great wealth. Yet he clearly loved his chosen field. His work with the IIT Research Institute continued



Marvin Camras sits in front of his magnetic tape recorder and other sound recording equipment. (Time & Life Pictures/Getty Images) through 1987, and he continued to teach electrical engineering at the Illinois Institute of Technology until 1994, when he was well into his seventies. Camras was awarded an honorary doctorate from IIT in 1968. He was inducted into the National Inventors Hall of Fame in 1985 and was also awarded the prestigious National Medal of Technology from President George H. W. Bush in 1990.

Camras lived for most of his adult life in Glencoe, Illinois. In his private life, the pioneer of sound recording techniques enjoyed playing the harmonica and making violins and violas. Some of the instruments he designed were used by his daughter, Ruth Camras Prickler, a musician and music teacher, and son-in-law, Charles Prickler, head of the Chicago Symphony Orchestra. Marvin Camras died of kidney failure on June 23, 1995. He was survived by his wife of many years, Isabelle Pollak Camras, four sons, a daughter, and six grandchildren. In an obituary published in *The New York Times*, Ray Dolby, the chairman of Dolby Laboratories, Inc., maker of professional sound equipment, praised Camras's contributions to the field of sound recording, calling him "a legend" whose basic designs and discoveries are still used in tapes and recorders.

MAGNETIC TAPE RECORDING

Marvin Camras was not the first person to invent a technique for sound recording. His magnetic wire recorder, first designed in the late 1930's and accepted for patent in 1944, drew upon the work of earlier inventors, especially Valdemar Poulsen. Camras's unique contribution made the process easier, better, and ultimately more accessible. His wire recorder used a magnetic recording head that surrounded the wire, preventing tangling and providing a superior sound. Camras went on to improve his original invention by creating magnetic coated tape that could be used instead of wire. Coated magnetic tape became the medium of choice for professional music and film recording equipment as well as home audio and videotape. Both the internationally famous rock band making a multitrack recording and the high school student taping an oral history interview on a minicassette recorder have Camras to thank for the technology that makes these recordings possible.

Magnetic tape recording takes many forms, but the basic mechanism remains the same: A tape that has been coated with magnetically active particles, typically ferric oxide and chromium dioxide, is passed through one or more magnetic tape heads. In essence, the particles coating the tape operate as small, individual magnets. The tape head operates as a magnetic field. As the tape passes around the head, the magnetic particles are activated and realigned. The process creates a magnetic pattern that remains on the tape until it is erased or rerecorded.

Camras's magnetic tapes and their coatings were for many years, and to some extent still are, the basis of most entertainment and data recording and storage in the United States and worldwide. While the magnetic recording process was originally developed for audio recording, later developments allowed it to be used for video recording, combining images and sound. The technology was also adapted for use in computer disks and magnetic credit card strips.

Camras's original wire recorder was used for strategic and training purposes during World War II, showing the versatility of the medium. The greatest impact of the magnetic recording technology, however, was on the broadcast and entertainment industries. Instead of a live radio or television broadcast, programs could be prerecorded and played, then replayed, at a later date. Instead of recording a song in one take, as musicians did in the early years of records, magnetic recording allowed songs to be created in multiple tracks and later mixed and edited into a single production. Some of the most innovative and acclaimed popular recordings of the rock era, such as the Beach Boys' *Pet Sounds* (1966) and the Beatles' *Sgt. Pepper's Lonely Hearts Club Band* (1967), could not have been created without multitrack recording.

IMPACT

Camras invented the magnetic tape recording method that became the basis of most electronic media, including audio and videocassettes, computer floppy disks, and credit card magnetic strips. His design of a magnetic tape head, used first in wire recorders and later in tape recorders, greatly simplified the recording and playback process and improved sound quality. His later work in high-frequency bias recording, multitrack recording, and related technologies further refined the clarity of sound reproduction. Camras's simple invention, born out of a desire to record a relative's singing, became a fundamental part of the multibillion-dollar music, film, and computer industries. Yet Camras himself shunned the spotlight, living a life marked by stability and continuity, working, teaching, and raising a family in the same midwestern community where he lived for most of his life.

Camras spent an impressive fifty-year career at the Armour Research Foundation and the Illinois Institute of Technology, where he taught from the 1940's until 1994. During those years, he earned more than five hundred U.S. and international patents for his work. His professional honors included the National Inventors Hall of Fame, the National Medal of Technology, and fellowships in the Institute of Electrical and Electronics Engineers (IEEE) and American Association for the Advancement of Science (AAAS).

—*Kathryn Kulpa*

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See also: Alexander Bain; Semi Joseph Begun; Charles P. Ginsburg; Peter Carl Goldmark; Les Paul; Alan Shugart; Charles Wheatstone.

CHESTER F. CARLSON

American physicist

Carlson invented xerography, a dry-copying process using electrostatic methods to reproduce documents and images on plain paper. The principles he outlined in his first patent applications remain fundamental to all existing plain-paper photocopiers and laser printers. Xerox copiers transformed the way business offices operated.

Born: February 8, 1906; Seattle, Washington
Died: September 19, 1968; New York, New York
Also known as: Chester Floyd Carlson (full name)
Primary field: Printing
Primary invention: Xerography

EARLY LIFE

All four of Chester Floyd Carlson's grandparents immigrated to the United States from Sweden in the mid-nineteenth century. His mother, Ellen Josephine Hawkins, and his father, Olof Adolph Carlson, both suffered from tuberculosis; a severe case of spinal arthritis incapacitated his father. Family poverty forced eight-year-old Carlson to begin seeking odd jobs; by high school, he was the main family provider, earning \$50 to \$60 a month. His mother died in 1923, leaving the high school junior the sole support of his father until he died in 1932.

Carlson enrolled in a work-study program at Riverside Junior College in Riverside, California, in 1925, alternating six weeks of classroom with six weeks of work. Completing the four-year program in three years, he was admitted to the California Institute of Technology as a junior, graduating with a physics degree in 1930. In that Depression year, his applications were ignored by more than eighty companies before Bell Telephone Laboratories in New York City hired him as a laboratory technician.

Repetitive lab work bored Carlson, who arranged a transfer to the company's patent department. After Bell fired him in 1932, he found a position with a patent attorney. In 1934, Carlson became a registered patent attorney based on his work experience as a patent clerk, although he could not practice in court. That year, Carlson joined the patent office of P. R. Mallory & Company, rising to manager of the patent department before resigning eleven years later. He married Elsa von Mallon in the fall of 1934. In 1936, Carlson enrolled in night classes at the New York Law School, spending his weekends studying at the public library. He received an LL.B. in 1939 and was admitted to the bar in 1940. The first marriage was not a success; the couple divorced in 1945, and Carlson married Dorris Helen Hudgins in 1946.

Carlson suffered from writer's cramp while copying long passages by hand from law books he could not afford to buy. He was irritated by the difficulty of producing error-free, multiple copies of patent specifications using carbon paper, and he knew how much it cost to have engineering drawings reproduced in special photocopy shops. The world, he decided, needed an office copier to perform these tasks. While reading law at the public library, he also surveyed scientific literature on copying and believed he found a unique solution.

LIFE'S WORK

Others also sought to produce convenient copiers, most investigating chemical and photographic possibilities. Carlson rejected those approaches, knowing he would be competing with large corporations, such as Eastman Kodak, employing squadrons of engineers and scientists. Instead he turned to physics, searching for a process that would produce images on plain paper without using chemicals. He discovered an article by a Hungarian scientist describing experiments using electrostatic principles to produce an image by directing a beam of ions to a rotating drum covered with insulating material.

Uniquely, Carlson conceived the idea of combining the properties of electrostatics with photoconductivity. No one else anywhere thought of this as a way to copy documents. He proposed using light to clear electrostatic charges from non-image areas on a plate. This needed a material that acted as an electrical conductor in light and an electrical insulator in the dark. If light shone an image of a printed page on an electrostatically charged plate covered with such material, the charge would be removed from the blank areas of the plate, leaving only the image charged. Dusting the plate with an opaque powder of the opposite charge would create a negative image that could be transferred to a sheet of paper, producing an exact copy of the original.

Carlson filed a patent application describing his idea in 1937. He elaborated it the following year, incorporating what he had learned in experiments. Carlson had difficulty making his idea work until he hired a refugee German scientist in October, 1938; the two produced the first xerographic image on October 22. In 1942, Carlson received an expanded patent establishing the foundation principles of what later became called xerography and that are basic to all xerographic machines.

Approaches to over twenty major manufacturing corporations during the next six years aroused little interest; International Business Machines (IBM) considered but decided against pursuing his invention. In 1944, the Battelle Memorial Institute of Columbus, Ohio, agreed to develop commercial applications of Carlson's process. The history of the next sixteen years demonstrates how difficult it can be to translate a brilliant invention into a commercially successful product, requiring the work of dozens of scientists and engineers before introduction of the Xerox 914 in 1960.

Battelle, a well-known and successful industrial research organization, had no more success than the obscure inventor in interesting a large corporation in Carlson's patent. Only the Haloid Company, a small manufacturer of photographic paper in Rochester, New York, requested a license, which Battelle granted in 1946 despite serious doubt that Haloid had the resources to finance needed research. Meanwhile, Battelle scientists discovered a better insulator to coat the plate involved in Carlson's process and found more efficient chemicals to carry out the complex procedures needed to produce an image.

As Haloid became central to the development of his patents, Carlson moved to Rochester in 1949 as a consultant. Unlike inventors who contribute to many fields, Carlson concentrated on xerography; of his forty-two patents, all but two dealt with copying.

Haloid's 1949 Model A machine proved a failure as an office copier. It was big, clumsy, and required many manual operations. However, when users of lithographic machines discovered that it cut costs of creating a master copy by almost 90 percent, companies employing lithographic machines began adopting it. Copyflo machines introduced in 1954 used xerographic principles to print from microfilm. Neither machine was the office copier that Carlson had envisioned.

The president of Haloid, Joseph C. Wilson, proved as fixated on the concept of a plain-paper office copier as Carlson and effectively bet his company on achieving that goal, spending on research during the 1950's more than his company's entire earnings. Recognizing his company's limited experience with machinery production, Wilson asked IBM to manufacture and market the machines. IBM hired the renowned Arthur D. Little consulting company for advice; the company concluded that a desk-sized machine costing $2,000 to produce could not compete with currently available chemical-based desktop copiers priced as low as $99.50 and predicted that the market would be limited to a few thousand units. IBM rejected participation.

Wilson pushed doggedly ahead, buoyed by the results of a 1959 field test that placed a half-dozen machines with Rochester companies to discover problems that needed fixing. Difficulties seemed endless, as the copiers broke down repeatedly, but when Haloid tried to retrieve its machines, no tester wanted to give them back. Wilson decided to begin selling; the first commercial Xerox 914 (9″ × 14″ was the largest sheet of paper it could use) shipped in March, 1960.

Patent lawyer Carlson had kept a close watch on royalties from his invention. One estimate puts his eventual wealth at $150 million. Carlson spent his last years anonymously giving money to charities and civil liberties organizations. His wife's will (they had no children) completed the process of giving away his fortune to groups he admired. On September 19, 1968, Carlson died of a heart attack.

IMPACT

Despite skepticism over Haloid's advertising claims, and reliability problems that plagued Xerox machines for years, the 914 was a runaway success. *Fortune* magazine called it the most successful product ever marketed in America. It transformed the way every office in the world operated. Customers enthusiastically invented uses for the machines that even Carlson never anticipated. As profits poured in, the Haloid Company renamed itself Xerox. Royalties made Battelle one of the nation's wealthiest research organizations and Carlson a multimillionaire.

A federal official, asserting that copying on plain paper was impossible, wrote warning Xerox to desist; Xerox's lawyer responded by copying the letter on a brown paper bag, which he returned to sender. When a Xerox television ad showed a child making a copy for her father, the Federal Trade Commission sent an investigator to see if a midget had been sneaked into the commercial, as it seemed hard to believe that a child could work such a complicated machine.

Xerox solved the price difficulty that had seemed insuperable to business consultants by leasing the machines and metering use. Charging five cents per plain-paper copy, Xerox wiped out existing copiers using more expensive, chemically treated paper that made hard-to-read copies that often smelled bad and tended to curl as they aged.

XEROGRAPHY

When Chester F. Carlson tried to find a sponsor for his invention, he had no model to show. All he had was a crude, six-step process he demonstrated unsuccessfully to IBM but with greater success to Battelle: He coated a smooth plate with a layer of dielectric material, then applied an electrostatic charge to the coated plate; placing a printed page facing the plate, he used a bright light to shine an image of the document on the plate, releasing the charge on the plate where light struck unshaded areas; the plate was dusted with a charged powder, revealing the image; the image was transferred to a sheet of paper, where the image was fused by heat.

Carlson's demonstration involved difficult manual steps and produced fuzzy copies. What fired the imagination of the men at Battelle and Haloid was realizing that, by combining the principles of electrostatics and photoconductivity, Carlson had come up with a truly new and revolutionary procedure that made copies without using either photography or printing with ink.

Transforming Carlson's process into an office-sized copier engaged the talents of many scientists and engineers. Battelle chemists discovered that coating the plate with selenium greatly increased the sensitivity of the plate. Using optical projection of the image to the plate permitted copying two-sided originals and books. More efficient chemicals were found for the powder or toner that revealed the image. A cylinder proved better than a flat plate for transferring the image, which introduced new complexities to the projection system. The temperature needed to fuse the toner was high enough to occasionally start fires: The early 914 models came with fire extinguishers, which salesmen renamed "scorch eliminators."

Carlson wanted an automatic desktop copier, but cramming everything into such a small compass was beyond the engineering and manufacturing skills of Haloid. The first commercial xerographic machine, the Model A, was room-sized and required many hand operations. Slowly, engineers learned how to automate the process, but squeezing all steps into a desktop-sized box proved too much for 1950's technology; Haloid settled for the desk-sized 914. Research since 1960 has improved the reliability and reduced the size of xerographic machines. However, all xerographic machines still depend upon the six-step process Carlson invented in 1938.

New uses proliferated. In offices where it had been the practice to use routing slips to circulate memoranda, personal Xerox copies now went to every recipient. Making copies of copies became common. Even the annoying frequent breakdowns of the early examples actually proved advantageous. It was cost-effective to rent several machines, ensuring a functioning copier available when needed; the presence of more machines encouraged making even more copies.

—*Milton Berman*

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See also: William Seward Burroughs; Lewis Waterman.

WALLACE HUME CAROTHERS

American organic chemist

Carothers conducted innovative polymer chemistry research to create synthetic rubber and nylon, stronger than natural materials, which were industrially developed for widespread distribution in consumer and military products. His investigations helped professionalize polymer chemistry as a scientific field.

Born: April 27, 1896; Burlington, Iowa
Died: April 29, 1937; Philadelphia, Pennsylvania
Primary field: Chemistry
Primary inventions: Nylon; synthetic rubber

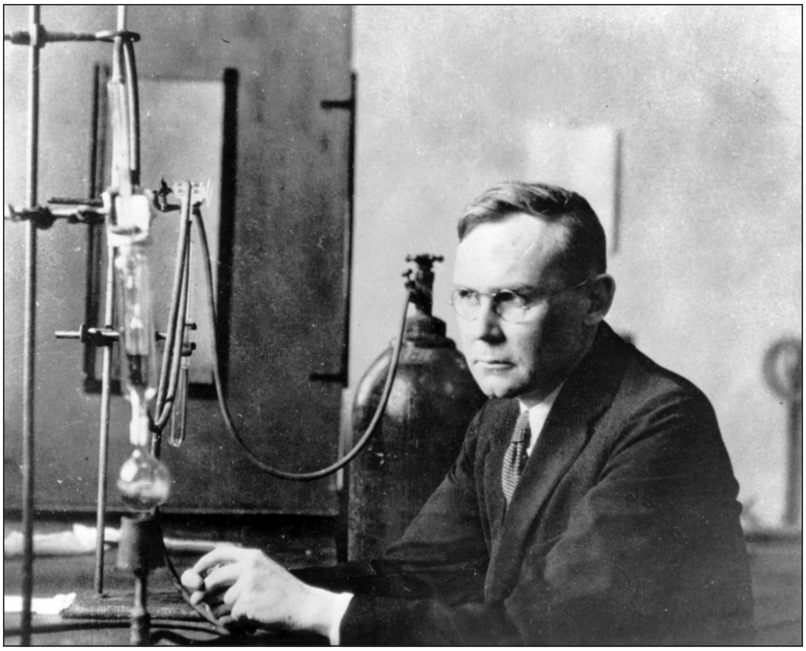
EARLY LIFE

Wallace Hume Carothers, born on April 27, 1896, in Burlington, Iowa, was his parents' first child. His father, Ira Hume Carothers, taught penmanship at the local Elliott's Business College. His mother, Mary McMullin Carothers, named her son Wallace to honor her mother's maiden surname. By the time of the 1900 U.S. Census, the Carothers were living in Mount Pleasant, Iowa, before moving to the state capital, Des Moines, when Ira was hired by Capital City Commercial College.

Carothers and his two younger sisters and brother attended United Presbyterian Church services with their parents, who were devout members of that denomination. He took classes at North High School and collected water meter data and worked in the city library's reference section for income. Science intrigued Carothers, who read Robert Kennedy Duncan's books discussing chemistry and built a chemistry laboratory in his bedroom.

After his 1914 high school graduation, Carothers completed the year-long business curricula at Capital City Commercial College, where his father had been promoted to vice president. Tarkio College, a four-year Presbyterian-affiliated school in northwest Missouri, sought students for its Commercial Department. Hoping to please church leaders, Carothers's father selected Wallace and another student to travel to Tarkio in September, 1915. Carothers earned tuition money as an assistant in the Commercial and English departments and as Tarkio president Reverend J. A. Thompson's private secretary.

Although Carothers took business courses, he sought a scientific education and within two years completed every chemistry class Tarkio offered. Department head Arthur McCay Pardee, who had been taught by Duncan, loaned Carothers his chemistry texts, which expanded Carothers's understanding of organic chemistry and German chemical research. Carothers devoted his laboratory work to investigating carbon. Disqualified for World War I service because of his goiter, Carothers taught chemistry at Tarkio, starting in 1918 when Pardee left for war work, until 1920 when he received his bachelor of science degree.


Wallace Hume Carothers. (Hagley Museum and Library)

LIFE'S WORK

Because Carothers aspired to become a professional chemist, he traveled to Urbana, Illinois, to enroll in graduate school at the University of Illinois, which Pardee had suggested would offer Carothers a challenging organic chemistry program. Roger Adams mentored Carothers and provided professional support throughout Carothers's career. After Carothers received his master of science degree in 1921, he taught chemistry courses at the University of South Dakota at Vermillion.

The next year, Carothers started doctoral work at the University of Illinois. In 1923, he published his first paper in the *Journal of the American Chemical Society*. Carothers completed his dissertation, "Platinum Oxide as a Catalyst in the Reduction of Organic Compounds," and received his Ph.D. in 1924. He remained at the university to teach until 1926. While at Illinois, Carothers endured intense emotional despair and purchased cyanide, telling people he might kill himself with the poison.

When Harvard University sought an organic chemistry instructor, Adams endorsed Carothers for that position. At Harvard, Carothers started investigating chemistry associated with polymers and large molecules. He preferred pure, not applied, science and did not actively seek industrial or commercial use of his findings. His research, however, attracted chemists' attention at both academic and industrial laboratories. Charles M. A. Stine, director of the chemical department at E. I. du Pont de Nemours and Company, contacted Carothers while searching for an exceptional organic chemist to develop synthetic materials for DuPont to produce. Carothers accepted, as he disliked teaching and considered focusing on research with a team of skilled chemists preferable.

Carothers moved to Wilmington, Delaware, and started his DuPont duties as research director on February 6, 1928. DuPont managers told Carothers to consider how his chemists might make synthetic rubber, needed because natural rubber was not easily obtainable, with an acetylene polymer. Intrigued by Hermann Staudinger's polymer work in Germany, Carothers tested that chemist's provocative 1920 hypothesis that polymers chemically consisted of long chains of large molecules.

In April, 1930, during their investigations to prove Staudinger's theory, the DuPont chemists developed the synthetic rubber neoprene from polymerized chloroprene made from acetylenes. DuPont trademarked that synthetic rubber as Duprene and commercially manufactured it, noting its resiliency to temperature extremes. In 1931, *Chemical Review* printed Carothers's paper "Polymerization," which discussed significant publications regarding polymer chemistry and explained related terminology and information to aid other chemists to pursue investigations in that emerging field. Carothers was associate editor of the *Journal of the American Chemical Society* from 1929 to 1937 and also edited the annual *Organic Syntheses* in the early 1930's.

After developing synthetic rubber, Carothers attempted to create synthetic polyester fibers with sebacic acid and ethylene glycol in his laboratory. When colleague Julian Hill removed a glass stick he had inserted into a polymer, some of the polymer stuck to the stick, stretching without snapping as he stepped away. The polymer threads remained pliable and strong when dried and cooled but dissolved in moisture and heat.

Carothers decided to pursue another project, creating the synthetic scent Astrotone. Elmer K. Bolton, who had succeeded Stine when he was promoted, pressured Carothers to continue his synthetic fiber investigations. In 1934, Carothers resumed research with large molecules from amines instead of glycols in an attempt to create fibers which were more durable when heated. He also explored the role of condensation in polymerization. Carothers and his chemists successfully made synthetic fibers on February 28, 1935. Fluent in German, Carothers met Staudinger at the September, 1935, Faraday Society meeting in England to discuss their work with macromolecules.

Despite Carothers's achievements, including approximately fifty DuPont patents identifying him as inventor and an invitation to head the University of Chicago's Chemistry Department, he perceived himself as inept, agonized that his synthetic fiber was useless, and doubted his capabilities. Carothers's intense work ethic, a failed romance, and alcoholism conflicted with his emotional stability. His ever-present cyanide vial and erratic actions alarmed DuPont managers and coworkers, who tried to reassure the fragile Carothers regarding his scientific merits and reduced his workload. In the summer of 1934, Carothers received psychiatric treatment at a Baltimore hospital.

On February 21, 1936, Carothers married Helen Everett Sweetman, a DuPont chemist who worked in the Patent Department. Four months after their wedding, she arranged for him to be admitted to a Philadelphia mental institution for several weeks. That year, the National Academy of Sciences chose Carothers as that group's first organic chemist member who researched for an industrial employer.

On April 9, 1937, Carothers filed a patent for DuPont describing his synthetic fiber. His depression had deepened when a sister died in January, 1937, and his wife revealed she was pregnant despite Carothers's insistence they not have children because of his mental instability. In late April, 1937, Carothers retreated to a Philadelphia hotel room, where authorities found his cyanide-poisoned body.

NYLON

Wallace Hume Carothers and his research team at DuPont investigated several chemical possibilities to create the first synthetic fibers before focusing on polyamides—polymers consisting of carbon, hydrogen, nitrogen, and oxygen molecules. The chemists made what Carothers referred to as a superpolymer when acids and alcohols, specifically molecules of adipic acid and hexamethylenediamine, both containing six carbon atoms, reacted. The chemists removed water from this superpolymer and pulled it into a thin flexible filament similar to silk threads but stronger. Carothers and DuPont personnel referred to that synthetic fiber as polyhexamethyleneadipamide, polymer 66, and fiber 66, before DuPont formally called it nylon—chosen from possible names DuPont workers suggested, including "Wacara" to honor Carothers.

DuPont, eager to manufacture nylon, began researching techniques and equipment to spin nylon filament, investing $8 million in a Seaford, Delaware, factory to make nylon yarn. Consumers bought approximately four million nylon stockings when stores initially sold nylon products in May, 1940. Before nylon presented options, U.S. manufacturers invested $70 million yearly in silk from Japan to make hosiery.

During World War II, nylon reinforced Allied troops' military equipment. Nylon strengthened uniforms, parachutes, and tents, and was used for aircraft tires and fuel tanks, ropes, and medical supplies. Some soldiers used nylon mosquito tents, while others were protected by nylon flak jackets. In 1945, DuPont produced 25 million pounds of nylon for wartime needs.

Nylon became DuPont's main income source after the war. The company increased nylon production to meet domestic demands and created almost 100 million pounds of nylon in 1949. Nylon became a popular fabric for clothing, expanding material choices and fashion possibilities. Other common products consisting of nylon are carpets, fishing lines, and toothbrushes.

The success of nylon motivated many chemists to make additional synthetics that had nylon's durability and versatility. Since nylon's invention, some scientists improved nylon by chemically designing it for specific uses. Others appropriated chemical knowledge used to produce nylon, supplemented with such technologies as computers, to expand polymer uses for medicine or invent such materials as Kevlar.

IMPACT

Carothers died without knowing how significant his synthetic fiber invention would become. His chemical innovations initiated industrial activity specifically devoted to manufacturing and selling nylon and neoprene. His inventions assisted economic recovery as the Depression ended and injected millions of dollars, then billions in later decades, into the U.S. and global economies, as well as increasing domestic and foreign trade as synthetics were incorporated in more products. DuPont employees, executives, and stockholders profited from Carothers's inventions; many became wealthy, and DuPont was able to invest in additional research while seeking a similar extraordinary invention as nylon.

In addition to enhancing economic conditions, Carothers's inventions and investigations advanced professional recognition of polymer research as an emerging branch of industrial chemistry. His successful work with macromolecules caused many chemists to reconsider their previous rejection of Staudinger's theories and pursue similar research. Industries sought chemists to investigate how to create synthetics with polymers to meet specific manufacturing and consumer needs and demands, escalating production. Staudinger noted that Carothers's successes with polymers and macromolecules contributed to acceptance of his research, which won him the 1953 Nobel Prize in Chemistry. Carothers's DuPont colleague Paul John Flory was awarded a Nobel Prize in 1974 for macromolecular research. If Carothers had lived longer, he might have also received a Nobel Prize for his groundbreaking work.

Although Carothers did not attain public fame during his lifetime, his inventions, primarily nylon, earned him posthumous acclaim. Nine years after Carothers's suicide, his DuPont colleagues named a nylon research laboratory located at Wilmington in his honor. The National Inventors Hall of Fame selected Carothers for induction in 1984. *The Wall Street Journal* profiled Carothers in May, 1989, as a significant figure in the history of U.S. commerce. In 1990, *Life* magazine listed Carothers among notable twentieth century Americans. In August, 1998, *U.S. News & World Report* declared that Carothers and nylon represented outstanding twentieth century innovation. The American Chemical Society and Chemical Heritage Foundation commemorated a Carothers centennial in April, 1996, and the laboratory where Carothers invented nylon was declared a historical chemical landmark four years later.

—*Elizabeth D. Schafer*

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See also: Charles Goodyear; Stephanie Kwolek; Charles Macintosh; Theodor Svedberg.

WILLIS CARRIER

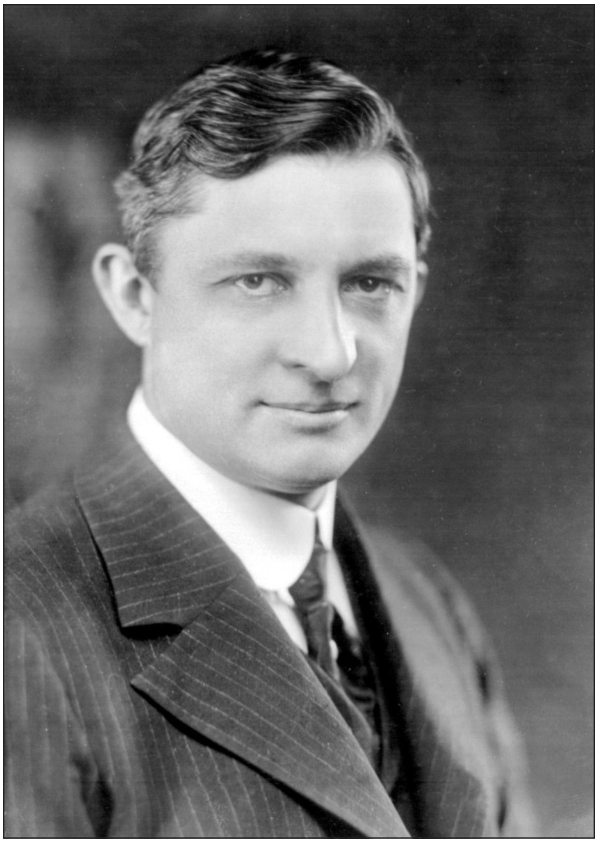
American engineer

Deemed by Time *magazine as one of the one hundred "Most Important People of the Century," Carrier was instrumental in the development of one of the most significant and quintessential inventions of the last hundred years, the air conditioner.*

Born: November 26, 1876; Angola, New York
Died: October 9, 1950; New York, New York
Also known as: Willis Haviland Carrier (full name)
Primary field: Mechanical engineering
Primary invention: Air conditioner

EARLY LIFE

Born the only child of older parents, Willis Haviland Carrier was the direct descendant of a prominent New England family that included an ancestor hanged by the Puritans during the notorious Salem trials of the seventeenth century. Carrier's father was a farmer, and his mother a "birthright" Quaker. Carrier grew up surrounded primarily by adults, including his grandparents and a great-aunt. Lacking siblings, he spent a great deal of time tinkering with any gadget he could find around the house. Surprisingly, however, he struggled with even the most fundamental math in school, having to slice apples into various parts so he could understand fractions. Although he was not regarded as a particularly motivated or industrious child, his marks in secondary school were sufficient to gain him a scholarship to Cornell University in Ithaca, New York. There Carrier studied electrical engineering while earning his room and board by stoking furnaces, mowing lawns, and taking in his classmates' laundry.



Willis Carrier in 1915. (Courtesy, Carrier Corporation)

Shortly after graduating from Cornell with a master's degree in 1901, Carrier landed his first professional engineering job. At the Buffalo Forge Company, he initially designed commercial heating systems to dry lumber and coffee. Within months after joining the company's research department, he had worked out a series of accurate tables used to calculate how much surface area would be needed to heat a given space. This, his first of many contributions to climate-control technology, saved Buffalo Forge $40,000 and catapulted Carrier to head of the department. He had overcome his childhood difficulties with math through rote trial-and-error experimentation and perseverance, traits that would soon lead him to develop one of the twentieth century's most important inventions.

LIFE'S WORK

Also while with Buffalo Forge, Carrier made several important discoveries related to industrial heating and humidity control and made his first forays into the industrial application of cooling methods. In 1902, he worked with Brooklyn, New York, printer Sackett-Wilhelms to control the excessive humidity that had previously wreaked havoc on the delicate conditions required for quality color printing. Not only did the "dew-point control" device he designed control humidity, but it also cooled interior air. Carrier had in effect designed the world's first mechanical air-conditioning system. He promptly applied for the first of what would eventually become hundreds of U.S. patents, for a mechanism that created a spray mist to regulate the air in a public ventilating system. His "manufactured weather" system was first installed at La Crosse National Bank in La Crosse,

THE AIR CONDITIONER

Although Stuart Cramer of Charlotte, North Carolina, originally coined the term "air conditioning" for a process he patented in 1906, it was Willis Carrier who is responsible for making the term widely known. The "dew-point control" device he conceived in 1902, through which moisture and ventilation are combined mechanically to control humidity and air temperature, is the basis for all modern air-conditioning systems. The air conditioner as it is known today works on basic principles not unlike the age-old practice of placing wet cloths in an open passageway to cool the area inside it. In the mechanical application, a chemical refrigerant is pushed through a series of evaporator coils. Hot air from the interior space is then forced over the coils via an intake fan. The refrigerant, which begins in a volatile liquid form, evaporates as it is exposed to the air and absorbs the desired amount of heat. Eventually the cooling air reaches its saturation point, causing the water within it to condense on a set of metal blades placed just above the evaporator coils. These blades, or fins, allow the moisture removed from the "conditioned" air to drain away while the cooled air is rereleased into the space. After the refrigerant fully vaporizes, it is fed into a device called the compressor. The compressor then forces the evaporated gas through a set of condenser coils, which are exposed to the outside air. This allows the refrigerant to return to a liquid form and release the heat it has absorbed through an exterior exhaust system.

The chemical composition of the refrigerants first used was for some time a significant obstacle to the air conditioner's functionality. Carrier's first air conditioner used a highly toxic and flammable refrigerant such as methylene chloride. Although this substance was initially considered acceptable for industrial cooling applications, it proved too hazardous for reliable home use. In 1928, Thomas Midgley, Jr., developed Freon, the first chlorofluorocarbon (CFC) refrigerant. Much more stable than the chemicals initially used in air conditioning, Freon (or R-11, as its producer DuPont called its first variant) paved the way for the safe and cost-effective use of air conditioning in homes, businesses, and other public places. In recent decades, however, CFCs have been found to cause significant hazards of their own. CFCs that have been gradually allowed to escape into the atmosphere are known to deplete the ozone layer, and their production and use have been curtailed if not prohibited in many countries throughout the world. The ozone-friendly alternative Puron (R-410A), which was developed in the mid-1990's, is now used as the primary refrigerant in today's more contemporary air conditioners and climate-control systems.

Wisconsin. In 1906, Carrier devised methods to help a South Carolina textile mill control the temperature of dangerously overheating fabric spindles, which led to his discovery of the "law of constant dew-point depression." He subsequently used this principle to design the automatic temperature control system, for which he was awarded his second patent. Carrier's engineering paper "Rational Psychrometric Formulae," published in 1911, laid the theoretical foundations of modern air-conditioning design.

While Carrier worked at Buffalo Forge, his potential for advancing the development of climate-control technology seemed limitless. However, in 1914, a setback occurred that influenced how Carrier did business for the rest of his life. At the prompting of frugal and shortsighted financiers, the company dismantled its engineering department, seeing no further need to put its resources into product development or innovation. Carrier and several other engineers were let go. Disgruntled but undeterred, he and Buffalo Forge salesman Irving Lyle raised $35,000 capital and formed their own company. Prior to Carrier Engineering Corporation, air conditioning had been regarded primarily as an industrial application. The cooling of machines, not people, was viewed as the only feasible commercial use for interior cooling devices. However, Carrier and his new partners saw vast potential in the development and production of air-conditioning systems for indoor temperature and air-quality control.

One major obstacle to cooling public spaces safely, however, was the flammable refrigerants used to cool industrial machines. In 1922, Carrier developed the first nonflammable coolant, as well as the first centrifugal refrigerating machine—the nexus of the two technologies that finally made safe and cost-effective air conditioning possible. By the mid-1920's, Carrier's new machine, propelled by the refrigerant methylene chloride, made his air-conditioning systems feasible for public use. The celebrated Grauman's Metropolitan Theater in Los Angeles, in addition to a handful of comparably sized theaters in Texas, became his first commercial clients. Also, by 1928, Carrier was able to expand the scope of his company's offerings, installing the first large-scale air-conditioning system in the twenty-one-story Milam

Building in San Antonio. In the same year, Carrier also made available the first home air-conditioning unit, which was gas-powered.

Carrier Corporation enjoyed monumental success even during the Great Depression, attesting to the fundamental appeal and prescience of its founder's inventions. In 1932, Carrier installed his first "centralized" air-conditioning system in Philadelphia's thirty-two-story Savings Fund Society Building. His ingenious design, which placed its cooling plant in the center of the building so as to allow efficient air flow equally to all floors both above and below the housing, remains the method by which high-rise buildings are cooled even today. Air conditioning was the toast of the renowned 1939 New York World's Fair. Through the 1930's and 1940's, Carrier continued to develop and introduce a host of innovations that led, in the subsequent decades, to making air conditioning as commonplace and essential as indoor plumbing or electricity.

Perhaps less well known, but just as significant, were the industrial temperature and air-quality control systems Carrier continued to develop and market until his death in 1950. As early as 1929, he had designed the air-conditioning system for the Morro Velho gold mine in Brazil that made deep-shaft mining possible. This development made the extraction of deep ground commodities as diverse as coal, diamonds, and rare minerals more feasible and efficient than had ever been thought possible.

IMPACT

Carrier was a remarkable figure. Although he died in 1950 just as the age of modern climate control was getting under way, his invention has affected the course of human development in the last half century in ways that only a handful of other technological innovations can claim. By controlling the unwanted heat and humidity often created as a by-product of large-scale manufacturing processes, Carrier's technology allowed countless industries to become more efficient. Modern cooling and climate control has paved the way for people to live, assemble, and interact in spaces never before dreamed of—including indoor theaters, concert halls, stadiums, and shopping malls. Without air conditioning, modern high-rise office complexes, hospitals, and apartment buildings would not be possible. Countless lifesaving drugs, chemical formulations, and industrial processes owe their existence to the precise climate control afforded by the technologies designed and marketed by Carrier.

Although seldom celebrated as an entrepreneur or business figure, Carrier also merits mention as one of the twentieth century's most important industrialists. Not only did he invent the device that makes much of modern industry possible, but he also founded and operated one of the world's largest corporations for over three decades. Affectionately dubbed "The Chief" by his employees, Carrier led Carrier Corporation until his death, and the company remained the largest independent heating and cooling business in the world until 1979, when it became a division of international conglomerate United Technologies. Carrier's products are still sold in 172 countries on six continents, a testament not only to the technological genius but also to the business acumen of one of the most important industrialists of the last hundred years.

—Gregory D. Horn

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See also: Frederick McKinley Jones; Roy J. Plunkett.

GEORGE R. CARRUTHERS

American astrophysicist

Carruthers designed and built the first space-borne ultraviolet light detector and camera and made the first measurements of ultraviolet emission from sources beyond Earth.

Born: October 1, 1939; Cincinnati, Ohio
Also known as: George Robert Carruthers (full name)
Primary fields: Aeronautics and aerospace technology; physics
Primary invention: Far-Ultraviolet Camera

EARLY LIFE

George Robert Carruthers was born to Sophia and George Carruthers on October 1, 1939, in Cincinnati, Ohio. His father was a civil engineer with an interest in astronomy. Young George received most of his primary education in the town of Milford, Ohio, where the family moved when he was seven. He grew up in the exciting first years of space exploration, when the idea of space travel was fanned by science-fiction books and films. His father encouraged him to learn about science and technology and fostered his son's interest in model rockets and astronomy. The boy built his first telescope at the age of ten.

Two years later, the Carruthers family suffered a great loss when George's father died suddenly, leaving the mother and four children. They moved to Chicago, Sophia Carruthers's hometown, in 1951, and George continued his education there, graduating from Englewood High School in 1957. Chicago offered excellent opportunities to learn about science because of its outstanding museums, especially the Field Museum of Natural History, the Museum of Science and Industry, and the Adler Planetarium, and George took advantage of these opportunities. His enthusiasm for space science was reflected in his joining the Chicago Rocket Society. Through his school, he entered several science fairs in which he received recognition for his scientific knowledge and inventiveness.

Following high school, Carruthers entered the University of Illinois, concentrating on physics, aeronautical engineering, and astronomy. After graduating in 1961 with a bachelor of science degree, he stayed on at Illinois for graduate work, obtaining a master's degree in the following year and a Ph.D. in 1964. His doctorate was in aeronautical and astronautical engineering. During his graduate career, he carried out several important experiments dealing with plasmas, especially in relation to plasma rocket engines and spacecraft reentry problems.

LIFE'S WORK

Carruthers's began his scientific career at the Naval Research Laboratory in Washington, D.C. He joined its rocket research group immediately after receiving his Ph.D., first as a National Science Foundation postdoctoral fellow and later as a research physicist in the Naval Research Laboratory's Hulburt Center for Space Research.

By 1964, space science had become a major activity in the United States. Orbiting spacecraft proliferated, and new opportunities for studying the planets and stars were opening up. One of these opportunities was the study of ultraviolet (UV) radiation emitted by cosmic sources. Ultraviolet light is absorbed by Earth's atmosphere, and ground-based scientists had not been able to detect it. Carruthers was interested in finding a good way to detect, measure, and study ultraviolet light from space. He carried out some experiments with suborbital sounding rockets, which reached high enough above most of the atmosphere to detect the ultraviolet light. In 1966, Carruthers's newly invented ultraviolet detector was successfully flown on a sounding rocket. In 1969, he patented the design for an ultraviolet camera, which was called an "Image Converter for Detecting Electromagnetic Radiation Especially in Short Wave Lengths." Subsequent experiments led to a major achievement in 1970 when his rocket-borne camera detected molecular hydrogen in space for the first time. Astronomers knew that hydrogen was abundant in the universe, as atomic hydrogen could be detected from the ground and was clearly the most common atom in space. However, in its molecular form, it had never been seen before, and Carruthers's camera proved an important new window into the universe.

Carruthers's results from rocket flights were impressive, especially considering the very short time the camera was above the atmosphere. To get better results, it was realized that the ultraviolet camera should be mounted on a telescope on a firm platform in space so that longer exposures could be made. The first opportunity for this came in 1972, when the Apollo 16 crew set up the Far-Ultraviolet Camera/Spectrograph on the lunar surface. Carruthers was the principal investigator and chief engineer for the experiment. The telescope and camera worked well, and the scientific results were superb, including UV images and spectroscopic data for both Earth atmospheric studies and stellar astrophysical measurements. In 1974, a backup camera from the Apollo mission was taken into space to be used on Skylab 4. Several experiments were carried out, including a first look at the UV light from a comet, as Comet Kohoutek was near the Earth at that time.

While satellite and lunar experiments were undoubtedly very productive, they were also very expensive and rarely available. For that reason, during this era Carruthers continued to use sounding rockets, which were much cheaper and more available, for science and engineering experiments. For instance, he was able to take advantage of the 1986 passage of Halley's comet to obtain some important ultraviolet observations of the hydrogen emission from the corona (the outer atmosphere) of this most famous comet.

In the 1990's, Carruthers was involved in using the Air Force's Advanced Research and Global Observation Satellite (ARGOS) for orbital study of the Earth's far-outer atmosphere, the electrically charged ionosphere and the neutral outer layers. His group developed a number of highly effective UV instruments for ARGOS deployment.

The Far-Ultraviolet Camera

The best-known of George R. Carruthers's inventions is the Far-Ultraviolet Camera, which Apollo 16 astronauts took to the Moon in 1972 to observe the ultraviolet (UV) light from several important astronomical objects. The experiment consisted of a miniature observatory, which included a telescopic camera, an altazimuth mounting, a table, and a tripod—all of which weighed twenty-two kilograms. The electronographic camera used a cesium iodide cathode to display the UV light and a film cartridge to record it. The telescope aperture was three inches in diameter, and the design was that of a Schmidt telescope with a focal ratio of f/1. The small observatory was mounted in the shadow of the Apollo Lunar Module in order to avoid direct sunlight and to have proper thermal conditions.

The astronauts operated the telescope according to a carefully determined plan, having practiced with the device on Earth. However, the Lunar Module had landed on a slope, so that if the telescope were set up as planned, its mount would be tilted, making the preplanned pointings incorrect. A resourceful astronaut solved that problem by jamming one of the tripod legs deeply into the lunar soil, leveling the telescope successfully. The astronauts were scheduled to adjust the direction of the telescope periodically to point it toward different objects. The telescope-camera design allowed it to record both UV images and spectra. In the latter case, the UV light was spread out into its different wavelengths. At the end of the mission, astronauts removed the film cartridge and brought it back to Earth. The telescope and camera were left on the Moon.

This experiment had an important impact on both astronomy and geophysics. Most of the objects studied had never before been imaged in the ultraviolet part of the spectrum. With Carruthers's camera, the Earth's outer atmosphere and its hydrogen-glowing geocorona were seen in excellent perspective. The nearby stars were recorded, and it was possible to measure accurately the temperatures of very hot stars for the first time, as they emit most of their radiation in the ultraviolet. Radiation from intergalactic hydrogen was seen for the first time, and the structure of the Milky Way was revealed in a new way. Even other galaxies were targeted. One of the most spectacular images was one showing the Large Magellanic Cloud, a neighbor galaxy 170,000 light years away, which was revealed to be lit up like a Christmas tree by the many UV-emitting hot stars spread across its face.

Impact

Carruthers was a pioneer in the field of ultraviolet astronomy. His Far-Ultraviolet Camera, set up on the Moon's surface by the Apollo 16 astronauts, produced about two hundred UV pictures of the Earth's far-outer atmosphere and deep-space objects. For the first time in history, his device detected hydrogen in deep space, and it accurately measured the energy output of very hot stars.

Carruthers has had a strong interest in teaching young people about science and its applications. In addition to talks to students at several universities, he is active in the work of Science, Mathematics, Aerospace, Research, and Technology (SMART), a group of scientists and engineers who provide training workshops for black teachers and students. Of the many awards that Carruthers has received, the most notable are the Arthur S. Fleming Award (1971), the Exceptional Scientific Achievement Award (1972), an honorary doctorate from Michigan Technical University (1973), the University of Illinois Alumni Award (1975), the Samuel Cheevers Award (1977), the Black Engineer of the Year Award (1987), and election to the National Inventors Hall of Fame (2003).

—*Paul W. Hodge*

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Carruthers, George. "Apollo 16 Far-Ultraviolet Camera/Spectrograph: Instruments and Operations." *Applied Optics* 12 (1973): 2501-2508. The ingenious and eminently successful Apollo 16 Far-Ultraviolet Camera, the first (and so far only) telescope to be used on the Moon, is described in detail. There are good diagrams and useful engineering details, but the paper is at a technical level.

_______. "Television Sensors for Ultraviolet Space Astronomy." In *Astronomical Observations with Television-Type Sensors*, edited by J. W. Glaspey and Gordon Arthur Hunter Walker. Vancouver, B.C.: Institute of Astronomy and Space Science, University of British Columbia, 1973. This is probably Carruthers's most important paper about his design and its relation to other instruments used for ultraviolet astronomy. It is fairly technical but well written, and it provides an excellent introduction to the engineering details of these kinds of instruments.

Henderson, Susan K., Stanley P. Jones, and Fred Amram. *African-American Inventors II: Bill Becoat, George Carruthers, Meredith Gourdine, Jesse Hoagland, Wanda Sigur*. Mankato, Minn.: Capstone Press, 1998. This short book is intended for high school-age readers. It provides the basic facts about the lives of five outstanding black inventors.

Kessler, James H., J. S. Kidd, Renée A. Kidd, and Katherine A. Morin. *Distinguished African American Scientists of the Twentieth Century*. Phoenix, Ariz.: Oryx Press, 1996. This encyclopedic book covers the lives and accomplishments of one hundred African American scientists and inventors. Its 392 pages are full of biographical data, arranged alphabetically and including a photograph of each person. Carruthers's biography is four pages long. The book was written for young readers in clear and rather plain language.

Orloff, Richard W., and David M. Harland. *Apollo: The Definitive Sourcebook*, New York: Springer Praxis Books, 2006. As the developer of the first telescope to be deployed on the surface of the Moon, George Carruthers was an important figure in the scientific success of the Apollo program. This thick and authoritative source book provides comprehensive accounts of each of the Apollo flights and summarizes the science attained. Its 633 pages are densely packed but are written in reasonably nontechnical language.

See also: Bernhard Voldemar Schmidt; Valerie L. Thomas.

EDMUND CARTWRIGHT

British clergyman

Cartwright's creation of the power loom was one in a series of significant eighteenth century inventions that revolutionized textile manufacturing, especially cotton textiles, in England and is considered part of the Industrial Revolution, which transformed England's socioeconomic structure.

Born: April 24, 1743; Marnham, Nottingham, England
Died: October 30, 1823; Hastings, Sussex, England
Primary fields: Business management; manufacturing
Primary invention: Power loom

EARLY LIFE

Edmund Cartwright's (KAHRT-rit) early life is not that well documented. His father, William, was a landowner in Nottinghamshire, England. William and his wife, Alice, had thirteen children, and Edmund was the fourth son. Edmund attended Wakefield Grammar School, graduated from University College, Oxford University, and was elected to a fellowship at Magdalen College, Oxford University, in 1764. He published a long poem, "Armine and Elvira," in 1770 and "Prince of Peace" in 1779. He pursued a career in the Church of England and became rector at Goadby, Marwood, Leicestershire, in 1779 and prebend of Lincoln Cathedral. Edmund's brother, Major John Cartwright (1740-1824), was a supporter of political reform during the reign of George III (r. 1760-1820). However, Edmund's fame was not to come from preaching, poetry, or politics; it came from inventing—an unexpected development considering his background and training. Edmund was married twice, first to Alice and then to Susannah after Alice's death.

LIFE'S WORK

Textile production in England had long been a significant sector of the economy. Because of the large number of sheep in England, the production of woolen cloth provided work for many villages through a process variably called the domestic or putting-out system or the cottage industry, whereby a cloth merchant would drop off raw wool to villagers who owned spinning wheels and handlooms. Inhabitants turned the raw wool into thread and bolts of cloth and then received payment from the merchants. The people worked at their own pace, with their families and at home. Working with family and friends to supplement their agricultural income became a social as well as an economic activity. All this would begin to change in the eighteenth century as the factory system developed, causing people to commute to work instead of working at home and to become subject to "industrial discipline" by being at work at an appointed time, only having an allotted time for meals, and receiving corporal punishment. There was also extensive reliance on child and woman labor.

The series of inventions started with John Kay's flying shuttle (1733), which allowed weavers to weave more quickly. Cotton began to become the preferred material to work with because of England's connections to the colonies of the American South, Egypt, and India. Because of the flying shuttle, weavers outpaced the spinners, and it was not until 1764 that James Hargreaves's spinning jenny allowed spinners to produce more thread and catch up to the weavers. In 1769, Richard Arkwright invented the spinning frame, also known as the water frame, which spun multiple threads into yarn; the large machine was powered by water and had to be housed in a building by a stream—in effect, a factory. Samuel Crompton in 1779 combined the spinning jenny and the water frame to create what is basically the modern spinning device—the spinning mule, or water mule.

In 1784, while Cartwright was on vacation at Matlock, Derbyshire, he met with a group of businessmen from Manchester, and they discussed the textile industry and the problem that resulted from Arkwright's water frame: Though the machine spun a great quantity of thread, it was difficult to weave the thread quickly into cloth. This meeting led to Cartwright's visit to Arkwright's textile mill in Derbyshire to view textile manufacturing firsthand. Cartwright was inspired to invent a weaving machine to complement the water frame. The first version that was produced with the help of a carpenter and blacksmith was modified, and Cartwright was awarded a patent for the device in 1785. The power loom was a very large, complex steam-powered machine that took two people to operate. The basic design was modified by Cartwright and other inventors to allow the machine to stop when the thread broke and to remove the finished cloth by rolling it off when the process was complete.

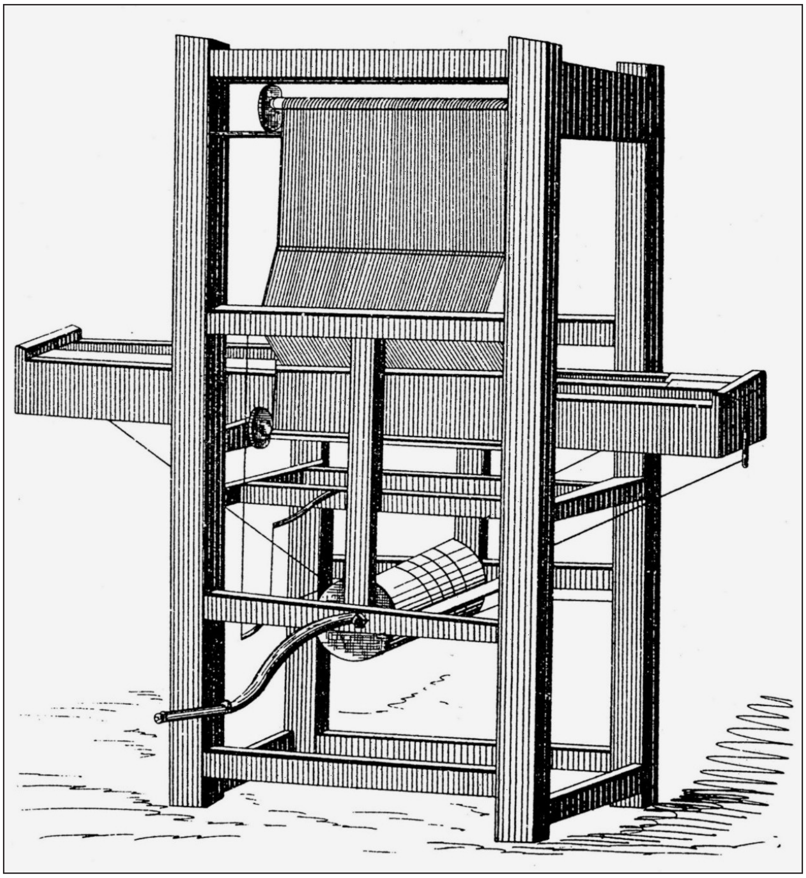
The relatively open social structure in England enabled a clergyman to become a textile entrepreneur by attempting to profit from his own invention. Although Cartwright built his own textile factories with steam-powered looms at Doncaster in 1787, he was not a successful businessman, declaring bankruptcy and shutting down in 1793—an apparent failure at age fifty. This also caused hardship for his brothers and sisters who had invested in his textile ventures. He did sell four hundred of his power looms to another manufacturing company, but that factory burned down. Local authorities and subsequent historians have suspected that arson on the part of disgruntled weavers may have been the cause of his factory's destruction. Before the mechanization of textile production, weavers were highly skilled artisans; now they had been reduced to fixing broken threads on machines or removing bolts of finished cloth from the power looms. This loss of prestige and even loss of employment caused many textile workers to petition authorities for redress, while others resorted to violence—smashing textile machinery, burning factories, and engaging in riots.

Cartwright continued tinkering and was awarded several additional patents. In 1790, he patented a woolcombing machine, and in 1792 he invented a machine for making rope. Finally, in 1797, he received a patent for an alcohol engine, similar to a steam engine in concept but using alcohol rather than water. One can understand the lack of success for this last device, as alcohol is more expensive and harder to obtain than water. In 1801, Parliament extended his patent for the power loom for an additional fourteen years, but in the following year, a textile manufacturer, William Horrocks, received a patent for an improved version of Cartwright's power loom that increased productivity. In 1807, Cartwright petitioned Parliament for recognition of the importance of his invention and for some monetary compensation. Robert Peel, a prominent member of the House of Commons and a wealthy textile manufacturer, supported this petition, and in 1809 Parliament voted a sum of £10,000 in recognition of the benefits that the power loom had bestowed upon England. This substantial payment helped Cartwright satisfy serious personal debt, as recent projects of his such as interlocking bricks and incombustible floorboards failed to come to fruition.

Cartwright had earned a doctor of divinity degree from Oxford University in 1806, and with his grant of money from Parliament he purchased a farm in Sevenoaks, Kent, where he lived a quiet, unassuming life. He died at Hastings, Sussex, and was buried at Battle, Sussex.

IMPACT

The power loom, along with the other textile inventions, produced major structural changes for all levels of British society. For the individual, factory work replaced working at home; families—husband, wife, and children—often ended up working in the factory, until the Factory Acts of the nineteenth century regulated working hours and conditions and banned work by children under certain ages. Many skilled artisans were reduced to textile workers who performed monotonous and even dangerous tasks in noisy factories that were hot in summer and cold in winter. There was no accident insurance



Edmund Cartwright's power loom, patented in 1785. (The Granger Collection, New York) or workers' compensation, so workers who were injured often lost their jobs. However, manufactured clothing became cheaper because cotton was easier to work with, and it was easier to care for and could be dyed various colors. Slowly, real wages rose, allowing workers to purchase manufactured products. Middle-class factory owners gained wealth, and during the nineteenth century they began to push for political power commensurate with their newly acquired wealth.

Localities changed because of the development of textile mills. It is estimated that there were more than two thousand power looms in England in 1810. As people left the countryside because of agricultural unemployment caused by the enclosure movement that forced farmers of smaller parcels off their land, they moved to work in textile mills, causing those industrial areas to explode into massive cities of several hundreds of thousands of inhabitants within a few decades. Such rapid urbanization brought significant problems: overcrowded slums of substandard housing, pollution, crime, prostitution, and disease. For example, Manchester grew in population from about 25,000 in 1772 to almost 370,000 by 1850.

England became known as "the workshop of the world" and increased its economic power many times over, especially through exports of textiles and other items produced by factory labor. Until the late nineteenth century, England's exports were larger than the combined exports of a number of European countries. England's influence in India through the East India Company expanded because of the export of manufactured cotton textiles to India that nearly ruined India's own hand-produced textile industry. In the twentieth century, Mohandas Gandhi's protest movement against British domination of India included ritual spinning of cotton thread to promote economic self-reliance and political independence.

—*Mark C. Herman*

THE POWER LOOM

Edmund Cartwright noted that the weaving process had three components that followed one another and that it would not be difficult to create a machine that would replicate these movements. He came to these conclusions in spite of the fact that the Manchester businessmen with whom he discussed the textile industry believed that it was impossible to create a mechanical weaving machine. Cartwright's original notes and drawing apparently do not exist, so the exact nature of his creative process cannot be reproduced or described except in the general summary he mentions in his writings. The warp portion was placed in a perpendicular fashion, and the shuttle was moved by springs attached to a cylinder under the loom. Cartwright noted that the springs were extremely strong and that it required the strength of two men to work the loom, but the pace of weaving was very slow. Because of the tension in the springs, the two men tired quickly; thus, the loom could only be operated for a brief period.

The biggest modification that Cartwright made was to reposition the warp horizontally and add a drive shaft to connect it to a power source, so that the strong springs could move the shuttle. Apparently, the first power source used was a bull, then the much more practical and efficient steam engine. Among the problems that Cartwright faced was patent infringement, which involved him in lawsuits to protect his invention from piracy.

FURTHER READING

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Strickland, Mary, and Jane Margaret Strickland. *A Memoir of Edmund Cartwright: A Memoir of the Life, Writings, and Mechanical Inventions of Edmund Cartwright*. 1843. Reprint. New York: A. M. Kelley, 1971. Although an older work, this book contains the most complete biographical information about Cartwright and captures the immediacy of his achievement, as it was published shortly after his death.

Weightman, Gavin. *Industrial Revolutionaries: The Creation of the Modern World, 1776-1914*. London: Atlantic Books, 2007. This work is strong on the importance of the individual inventors and entrepreneurs and the social and economic impacts of industrialization.

See also: Sir Richard Arkwright; James Hargreaves; John Kay.

GEORGE WASHINGTON CARVER

American agriculturalist

Carver is most famous for the large number of by-products that he derived from the peanut, sweet potato, and several other crops, but his achievements in the revivification of Southern agriculture and the advancement of African American education were also notable.

Born: July 12, 1861?; near Diamond Grove (now Diamond), Missouri
Died: January 5, 1943; Tuskegee, Alabama
Also known as: Plant Doctor
Primary fields: Agriculture; chemistry; food processing
Primary invention: Peanut milk and other by-products of sweet potatoes and peanuts

EARLY LIFE

The person who came to be called George Washington Carver was born a slave, and because documentation about slaves tended to be thin, considerable uncertainty exists about his early life. He took his last name from his owners, Susan and Moses Carver, and in later reminiscences he stated that he had been born near the end of the Civil War, though some scholars give dates as early as 1860 or 1861 and others opt for 1865. Material issued by the George Washington Carver National Monument gives his birth date as July 12, 1864. His mother, Mary, had a previous son, Jim, and his father, according to Carver, was a slave on a neighboring farm who had been killed in an accident. What is certain is that George grew up in Missouri on the Carver farm, located near a diamond-shaped stand of trees in the village of Diamond Grove.

A tragic event that influenced George's life occurred when he and his mother were kidnapped by Confederate raiders and taken to Arkansas. Eventually, Moses Carver was able to locate George and barter him back in exchange for a racehorse, but Mary was never found and was assumed to have died. After the end of the Civil War, George and his brother Jim were adopted and raised by the Carvers. Because of his frail health, George worked at household tasks rather than in the field, but, as a young boy, he exhibited a deep curiosity about nature, and he collected wild plants and raised them in his own garden. His skill in nursing sickly plants to health led to his being called the "Plant Doctor."

George's early education occurred at a church school, and he became a Christian when he was ten years old. After his prayers for improved health were answered, his faith in a benevolent Providence solidified and became a defining characteristic throughout his life and scientific career. As a teenager, wishing to further his education, he was allowed to attend a school for "coloreds" in Neosho. He then led a peripatetic existence until he was finally able to get a high school education in Minneapolis, Kansas, where he worked in a laundry and added "Washington" as his middle name to distinguish himself from another George Carver.

After being rejected by a college because of his race and after a failed attempt at farming on the Kansas frontier, he moved to Iowa, where he enrolled at Simpson College as its first African American student. There he met Etta Budd, an art teacher who encouraged him to switch from art to botany and to transfer to Iowa State College of Agriculture and Mechanic Arts (now Iowa State University), where her father was a professor of horticulture. In 1891, he became the first African American to be accepted by Iowa State. By working in the agricultural laboratory, he was able to pay his college costs while also doing well in his academic subjects. His thesis for his bachelor's degree centered on his experiments with plant hybrids. In 1894, he became the first African American to graduate from Iowa State. He remained at Ames to obtain his master's degree, following which he accepted an offer to become the college's first black faculty member. He taught botany and conducted plant experiments, while managing the college's greenhouse.

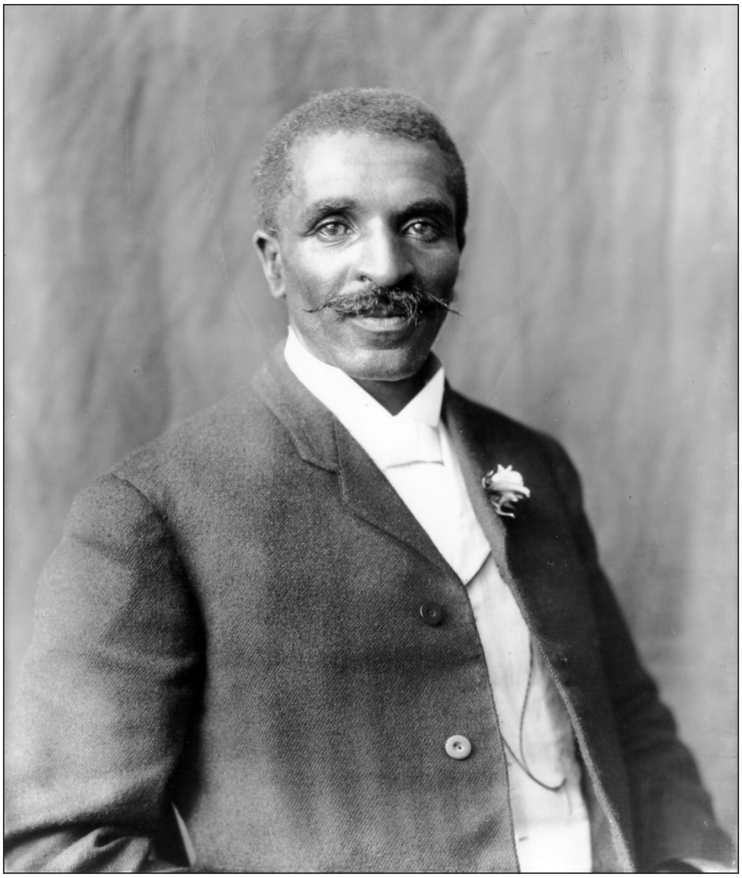
LIFE'S WORK

Booker T. Washington, who had founded the Tuskegee Normal and Industrial Institute for Negroes (now Tuskegee University) in 1891, had learned of Carver's achievements, and in 1896 he invited him to head Tuskegee's Department of Agriculture. Carver accepted and traveled to Alabama, beginning what would become a forty-seven-year association with this institution. Initially, he was confronted with challenges, such as the department's meager facilities of a barn and a few farm animals. By scavenging the institute, he was able, using his improvisatory skills, to create and equip an agricultural laboratory, which became the site of his and his students' research. He also had to overcome the negative attitude of faculty members who disparaged agricultural work, associating it with sharecropping, but Carver made his first important contributions by showing sharecroppers and other small farmers how to improve their harvests.

For decades, Southern farmers had been growing cotton and tobacco with diminishing returns, and Carver recognized that their problems were due to soils that had become seriously depleted in nutrients. Through his experiments, bulletins, and visits, he was able to convince an increasing number of farmers to alternate their plantings of cotton with such leguminous plants as peanuts, which enriched the soil with nitrogenous compounds. He was rewarded for his efforts when the state of Alabama passed a bill to support an Agricultural Research Station at Tuskegee. From 1903, when his peanut studies began, until 1915, when Booker T. Washington died, he developed many recipes that contained peanuts and many by-products that he derived from peanuts. The farmers who followed Carver's advice were so successful that their high yields created a problem, for when markets became saturated with peanuts, their price dropped. This stimulated Carver's inventiveness, and he developed a large number of uses for the excess peanuts. To farmers and members of the peanut business he became known as the "Peanut Man."

In 1916, Carver published what turned out to be his most popular bulletin. It was on 105 ways of preparing the peanut for human consumption. For example, the fifty-first recipe was for peanut butter, which led some to the erroneous conclusion that he was its inventor. He had already derived many products from soybeans and sweet potatoes, but the favorable response to his recipes led him to discover many other uses for the peanut. Over the years, several authors have claimed that Carver derived more than three hundred products from the peanut, but later scholars questioned this claim. Because Carver publicized his discoveries through bulletins, speeches, and demonstrations, and because he kept inadequate laboratory notebooks and eschewed publication in scientific journals, it has been difficult to substantiate many of his discoveries. However, studies have shown that his lists contain redundancies, unoriginal products, and products that are simple combinations of previously known materials. When these are removed, the list contracts to about a hundred. These include such food products as cheeses, milk and meat substitutes, and flour; such cosmetics as face powder, face and hand lotion, and shampoo; and such general products as medicines, dyes, paints, and stains. Carver's methods were largely trial and error. Using chemical solvents, he would extract materials from his peanut plants and then combine these extracted materials with other substances in the hope of creating a useful product. He published his most interesting results in his bulletins and exhibited his food and cosmetic products at state fairs and other venues, but, as his later critics have pointed out, not one of these became a successful commercial product. Nevertheless, his ability to make so many things from the peanut excited the public imagination.

After Washington's death, Carver formed a close friendship with his successor, Robert Russa Moton. Moton's tenure as president lasted to 1935, and during this time Carver, now free from classroom and administrative obligations, was able to de-



George Washington Carver during his early years at Tuskegee University. (Library of Congress) vote himself fully to agricultural research. His studies of soils and his investigations of such crops as sweet potatoes, soybeans, and pecans led him to make a large number of products. For example, he most famously derived 118 products from the sweet potato, but, as with the peanut, scholars have found repetitive and unoriginal entries and have reduced the list to forty uses—including his recipes for sweet potato flour, starch, and sugar bread.

Although Carver did not single-handedly revolutionize Southern agriculture by his advocacy of the peanut, sweet potato, and other crops, the American peanut business prospered because of his example and the work of many others. The U.S. peanut business became so large that it felt threatened when China-grown and Japan-processed peanuts undersold the U.S. product. In 1921, Carver, testifying in favor of a protective tariff before the House Ways and Means Committee, helped persuade its members that the American peanut industry was well worth saving, and a tariff on imported peanuts became the law. His successful appearance before Congress increased his fame, and he received many invitations to speak around the country as well as several job offers—including one from Thomas Alva Edison—all of which he refused, preferring to remain at Tuskegee.

PEANUT MILK

George Washington Carver's discovery of peanut milk contributed to his fame as the "Peanut Man." He certainly had dreams for its commercial success. He did not see it as a substitute for cows' milk but as an important new supplement to the human diet. The peanut was rich in protein and other nutrients, and he hoped that it might also serve as a replacement for those unable to consume cows' milk.

As with many of his other inventions, Carver created peanut milk by a process of trial and error. He knew that peanuts contained a high percentage of oil and that they also contained varying amounts of proteins, carbohydrates, and fats. His peanut milk was an emulsion of these oils, fats, proteins, and carbohydrates. In fact, he made several kinds of peanut milk by varying the proportions of some of these components and by adding water. Like oil in vinegar, peanut oils in water formed an emulsion, a suspension of tiny globules, since the two liquids are immiscible. Carver, who first made peanut milk in 1919, was very happy with his creation, using it to make tasty bread and creamed vegetables.

On September 22, 1919, Carver informed Dr. Robert Russa Moton, Tuskegee University's president, of his discovery, and Carver began to publicize his new product in speeches. This information soon reached members of the peanut industry in Alabama, and Carver was invited to speak about peanut milk and his other peanut derivatives at a 1920 meeting of the United Peanut Association in Montgomery, Alabama. When he arrived, he, as a black man, was not allowed to enter the convention hall by the front entrance, but he was finally allowed to reach the meeting hall through a rear entrance. He then lectured the delegates about the virtues of peanut milk, which, he stated, could be made more quickly and efficiently than a cow produces milk. His talk was enthusiastically received, and several delegates wanted to facilitate the commercial development of peanut milk. However, Carver's hopes for its commercialization were frustrated when he learned of a patent for peanut milk that had been filed in England in 1917. Carver believed that his product was superior to the English version. He went on to make thirty-two kinds of peanut milk, but he never patented any of his formulas. Nevertheless, Carver's advocacy of his creations proved to be beneficial for the peanut industry, since it was his life and personality, not his peanut milk, that ultimately excited the public.

In 1923, he agreed to lend his expertise and name to a company that was being formed to develop commercially some of his agricultural derivatives. The Carver Products Company would actually manufacture no products but sell some of Carver's processes to concerns that did. With this in mind, Carver, for the first time in his career, had to patent his products and processes: On January 6, 1925, he was granted a patent for cosmetics and his process for making them; on June 9, 1925, he received a patent on paints and stains along with the processes for making them; and on June 14, 1927, he obtained another patent on his formulas for making paints and stains. With the incorporation of the company bearing his name, Carver garnered much favorable publicity, but the company was insufficiently capitalized and poorly managed, and it eventually failed. Similarly, the Carver Penol Company was founded a few years later to market Carver's discovery of an emulsion of creosote and peanut juices. Physicians had long used creosote as an antiseptic and a remedy for bronchitis, but it had a nauseating taste. Carver's idea was to create a palatable mixture that would synergistically combine the medicinal properties of creosote and the nutritive values of peanuts. Carver called the combination Penol, and he tried it on himself. He found its taste pleasant, and it cured him of a persistent cough. Some physicians tried it on their patients and reported successes. By the mid-1920's, some prominent businessmen formed the Carver Penol Company and raised sufficient capital to construct a small factory to make bottles of Penol. The company lasted into the 1930's, but because of poor sales and a Food and Drug Administration (FDA) report in 1937 that invalidated Penol's nutritional and medical claims, the Carver Penol Company eventually failed.

During the 1930's, Carver became an important part of the chemurgy movement, which advocated the development of commercial chemicals from agricultural products. In 1937, he attended two chemurgy conferences, at one of which he met Henry Ford, and they became friends. In fact, Ford and other important members of this movement considered Carver to be its "patron saint." Despite his growing fame and influence, he witnessed his work at Tuskegee decline because of lack of funding brought on by the Great Depression. He was also old, and his health began to fail. In 1941, Ford came to Tuskegee to dedicate the George Washington Carver Museum, and Carver himself established a foundation to continue his work at Tuskegee. After a fall down a flight of stairs, he was hospitalized, and he died from various complications, including anemia, early in 1943. He was buried near Booker T. Washington at Tuskegee, and his epitaph epitomized an idealized view of his life: "He could have added fortune to fame, but caring for neither, he found happiness and honor in being helpful to the world."

IMPACT

Even though Carver patented only three from his lists of more than five hundred crop derivatives, recipes, and by-products, he became famous as an agricultural inventor. His accomplishments had a significant influence on the African American community, and he received the Spingarn Medal of the National Association for the Advancement of Colored People (NAACP). His contributions to Southern agriculture were honored by the Roosevelt Medal in 1939. Posthumously, his honors multiplied with his election to the Hall of Fame for Great Americans (1977) and his induction into the National Inventors Hall of Fame (1990). He was commemorated in two U.S. postage stamps (1947 and 1998), a Polaris submarine was christened the USS *George Washington Carver*; and his Missouri home was made into a national monument.

The glorified story of Carver's rise from a slave to a great scientist fascinated the public of all races, and *Time* magazine called him the "Black Leonardo," because, like da Vinci, he contributed not only to science but also to art (he was an accomplished painter). After his death, hagiographies written for children and general audiences established the image of Carver as a saintly scientist and inventor whose advocacy of the peanut had helped save Southern agriculture. In recent decades, as scholars have corrected the errors in this idealized portrait, Carver's influence has lessened, particularly among scientists. Because he did not participate in meetings of professional scientific organizations and failed to publish his results in refereed journals, his discoveries and inventions have been criticized. His status among business historians has also diminished as it has become widely known that not one of his agricultural by-products ever achieved commercial success. On the other hand, in an age of increasing environmental sensitivity, some scholars have praised Carver's support of sustainable agriculture at the local level, where efficient use is made of all parts of crops. Enlightened scholars now view Carver more as a naturalist than a scientist, someone whose religious beliefs ally him with modern holists rather than with reductionists and industrialists. Ultimately, his motivating vision was of a multiracial America in which carefully conserved land supported people living modestly, healthily, and happily.

—*Robert J. Paradowski*

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See also: Henry Ford; Percy Lavon Julian; Eli Whitney.

GEORGE CAYLEY

British aeronautical engineer

Cayley founded the science of aeronautics by identifying the controlling forces on an airplane in flight. He designed and flew a fixed-wing glider airplane that lacked only two modern innovations: movable wing flaps (ailerons) for roll control, and a power plant.

Born: December 27, 1773; Scarborough, Yorkshire, England
Died: December 15, 1857; Brompton, Yorkshire, England
Primary field: Aeronautics and aerospace technology
Primary invention: Monoplane glider

EARLY LIFE

George Cayley was born in Scarborough in Yorkshire, England, on December 27, 1773. His mother, Isabella Seton, was from a prominent family that was distantly related to Anne Boleyn, one of the unfortunate brides of Henry VIII. His father was Thomas Cayley, and his grandfather, also of the name George Cayley, was the fourth baronet of Brompton. ("Baronet" is a hereditary title reserved for commoners, superior to all orders of knighthood other than the Order of the Garter, but inferior to full barons.) Thomas, in turn, became the fifth baronet of Brompton at the age of sixty-two when Sir George the elder died. The younger George Cayley inherited the title eighteen months later upon Sir Thomas's death in 1792.

Family lore says that the young Cayley had an intense interest in mechanical devices and was allowed to spend a great deal of time annoying the village watchmaker. Cayley was primarily educated through the services of two tutors. The first was George Walker, minister of High Pavement Chapel in Nottingham and fellow of the Royal Society of London for the Improvement of Natural Knowledge, Great Britain's premier learned society. It stood at the center of the scientific discoveries and technological developments of the time. Through Walker, Cayley felt the influence of Britain's finest minds. Walker also possessed strongly liberal ideas in both politics and religion; presumably, Cayley was influenced by these ideas as well. Cayley's mother chose George Cadogan Morgan, very similar to Walker in many ways, to be Cayley's tutor starting in 1792. The Walker influence quite likely continued throughout Cayley's life: He married Sarah Walker, George's daughter, in 1795.

Cayley's accession to the baronetcy of Brompton brought him large estates, significant wealth, and important responsibilities. The rest of Cayley's life would be an equal mixture of agricultural management, political leadership, scientific research, and engineering projects. One measure of his genius was his skill at filling these roles.

LIFE'S WORK

Cayley's interest in flight started at a young age. He began, like so many others before him, by studying the flight of birds. Previous investigators thought of human or mechanical flight almost exclusively in terms of flapping wings, always based on the mistaken belief that bird wings flapped simultaneously downward to generate lift and backward to generate thrust. Designs for flying machines, such as Leonardo da Vinci's ornithopter, relied on this thinking. One of Cayley's earliest scientific observations was that birds flap their wings downward only but warp their wings to achieve forward thrust.

An engraved silver medallion produced by Cayley in 1799 shows an aircraft design on one side that incorporated a fixed wing for the generation of lift and a separate mechanism for the generation of thrust. Cayley, for the first time in aeronautical history, divorced the generation of lift from the generation of thrust. This became a central tenet of aeronautical development over the next century, finally achieving reality with the success of Orville and Wilbur Wright in 1903. (Simultaneous generation of lift and thrust from a rotating wing was eventually realized in the development of the helicopter.) The other side of the medallion shows the aerodynamic force on an inclined plane functioning as a fixed wing. The force is properly resolved into the two components of lift and drag, demonstrating that at this early date, Cayley possessed a full appreciation of the fixed wing and its application to flight.

Cayley, like others before him, investigated these forces experimentally for insight into the physics of flight. In the 1820's, he used the whirling-arm apparatus invented by Benjamin Robins in 1742. This continued to be the instrument of choice for the testing of airfoils and for measurements of lift and drag until the Wright brothers adopted and improved the wind tunnel, an 1871 invention of Francis Wenham and John Browning.

THE MONOPLANE GLIDER

George Cayley's most sophisticated aircraft design appeared in *Mechanics Magazine* on September 25, 1852. Called the "governable parachute," it was in fact a human-carrying glider. Cayley regarded gliders and parachutes to be of the same class since they rely solely on gravity for maintaining airspeed. This 1852 glider design, though probably never built and flown, was thoroughly modern in concept and approach to flight.

Airplanes have three independent degrees of freedom: pitch, the motion of the nose up or down in a vertical plane; yaw, the motion of the nose to the right or left in a horizontal plane; and roll, a rotation to the right or left about an axis stretching from nose to tail. Pitch is controlled by the elevators. Yaw is controlled by the rudder. Roll is controlled by the ailerons.

Nominal flight configuration has pitch, yaw, and roll all equal to zero. This is level flight with the nose pointed in the direction of travel. A stable airplane, one safe and comfortable to fly, spontaneously returns to nominal flight if disturbed; an unstable airplane spontaneously tends to dangerously increasing values of one or more of these motions if disturbed.

Cayley's aircraft, the 1852 design among them, were the first in history inherently stable in pitch and roll in straight or slightly curved flight, and the first equipped with pilot-controlled elevators and rudders. Rudder and elevator were combined into a single cruciform tail. Both were movable, giving the pilot true control over the aircraft.

The 1852 design incorporated dihedral wings for built-in roll stability, but it did not include ailerons or any alternative way of changing the shape of the wings, making the glider difficult to steer. Fixed-wing designs such as Cayley's have no way of initiating or controlling roll and therefore cannot initiate banking turns. While capable of true flight in a straight line, they can accomplish turns only with great difficulty and are not truly navigable in the air.

Cayley's 1852 design had no onboard propulsion. Other earlier designs incorporated movable flappers separate from the fixed wings to generate thrust in the manner of birds. Cayley knew of the propeller but believed his flapper approach to be superior. Overall, the propeller receives very little mention or regard in Cayley's writings. Further, Cayley's power plant designs were crude and ineffective—understandable at a time when the science of thermodynamics and the technology of heat engines were both in their infancy.

Cayley designed, built, and flew his first engineered glider in 1804. Although only a small handheld model (one meter long) and childish to modern eyes, it was the first aircraft in history possessing a fixed wing and adjustable tail consisting of a combined elevator and rudder.

Cayley published a tripartite paper, "On Aerial Navigation," in the *Journal of Natural Philosophy, Chemistry and the Arts* in November of 1809, February of 1810, and March of 1810. This paper was the first to document that flat surfaces inclined to the wind generate lift; that curved (cambered) surfaces do so more efficiently; and that lift is caused by a low pressure region above the wing. The paper also contains the first discussion of flight control achieved through vertical and horizontal tail surfaces and announces the first successful flight of a full-sized glider, flown unmanned at Cayley's estate in 1809.

From 1810 to 1845, Cayley's energies were consumed by other activities. He resumed his aeronautical research in 1848. His first manned aircraft flew in the spring of 1849. Cayley reported that some of the flights took place with a boy of ten years age on board. A second, presumably larger version of this aircraft flew with a man on board in 1853.

Cayley also patented an early version of the modern caterpillar tractor, experimented with hot air heat engines, built a crude one-cylinder internal combustion engine using gunpowder as fuel, and built the first movable artificial hand. He died in 1857 at the age of eighty-three.

IMPACT

Cayley's first publication on aerial flight garnered a small audience. It was reprinted several times during the later half of the nineteenth century. Cayley published his most important paper in *Mechanics' Magazine*, dated September 25, 1852. Despite the large readership of this periodical, Cayley's paper was immediately forgotten. His other inventions and innovations suffered similar fates.

Nevertheless, the unsung Cayley is sometimes credited as the "father of aviation," and rightly so. It was his pioneering work that paved the way for the Wright brothers' historic flight in 1903. Notably, Cayley discovered that the means of generating lift should be separated from the means of generating propulsion. His aircraft were the first in history that were inherently stable in pitch and roll in straight or slightly curved flight, and the first equipped with pilot-controlled elevators and rudders.

No one else combined all of Cayley's innovations in aerial flight until after the Wright brothers. Unlike Cayley, the Wrights chose a statically unstable configuration. In this regard, they took a step backward from Cayley's use of a rudder. Instead, they used wing warping (the generation of adequate thrust using an internal combustion engine) to initiate and control roll. This required constant input from the pilot to maintain control of the aircraft but also allowed the plane to execute banking turns. Further, the Wright brothers used a forward elevator in a canard configuration to achieve pitch control. A separate rudder in the rear controlled yaw. Airplane development subsequent to the Wright brothers returned to statically stable configurations closer to Cayley's approach.

Finally, the Wrights embraced the propeller. They were the first to analyze it as a "rotating wing," and as a result they were the first to wring enough thrust out of it for manned aerial flight. The Wright brothers also had the internal combustion engine to adapt to their needs. Wing warping and an efficient aerial propeller finally made it possible for the Wrights to make Cayley's dream of manned aerial flight a reality.

—*Billy R. Smith, Jr.*

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See also: ʿAbbas ibn Firnas; Emile Berliner; Sir Christopher Cockerell; Glenn H. Curtiss; Robert H. Goddard; Samuel Pierpont Langley; Bill Lear; Louis-Sébastien Lenormand; Leonardo da Vinci; Edwin Albert Link; Paul B. MacCready; Joseph-Michel and Jacques-Étienne Montgolfier; Hans Joachim Pabst von Ohain; Burt Rutan; Igor Sikorsky; Robert Stirling; Charles E. Taylor; Andrei Nikolayevich Tupolev; Faust Vrančić; Sir Frank Whittle; Sheila Widnall; Wilbur and Orville Wright; Ferdinand von Zeppelin.

VINTON GRAY CERF

American computer scientist

Cerf is one of a handful of individuals (along with Leonard Kleinrock and Bob Kahn) who is most frequently called the "father of the Internet." While a professor at Stanford, Cerf codesigned the packet network interconnection protocols that would come to be known as TCP/IP, which helped pave the way for the Internet.

Born: June 23, 1943; New Haven, Connecticut
Primary fields: Communications; computer science
Primary invention: Transmission Control Protocol/ Internet Protocol

EARLY LIFE

Vinton Gray Cerf was born six weeks premature on June 23, 1943, in Connecticut while his father was overseas serving in the Navy in World War II. After a brief stay in Tennessee, the Cerf family settled in California. Cerf's hearing loss became evident as early as nine years of age, yet he did not require hearing aids until he was in junior high. Cerf stood out from his fellow high school students because he regularly wore a coat and tie. He was also an avid reader of science fiction and fantasy and, as a student, fell in love with algebra. In 1961, he graduated from Van Nuys High School and headed to Stanford University.

Cerf obtained a bachelor's degree in mathematics from Stanford. After graduation, he took a job at International Business Machines (IBM) as a systems engineer supporting the programming language QUIKTRAN, an interactive FORTRAN time-sharing service. After just two years, he decided to return to graduate school at the University of California, Los Angeles (UCLA), where he earned his master's degree in 1970 and his doctorate in computer science in 1972. Cerf's doctoral thesis was based on work he did with the "Snuper Computer," the Defense Department's Defense Advanced Research Projects Agency (DARPA) project that was aimed at allowing one computer to remotely observe the operation of another. As a result of his work with the Snuper Computer, Cerf began work with the Network Measurement Center at UCLA, a program designed to performance-test network traffic flow. During his time at UCLA, Cerf worked with Leonard Kleinrock and, in 1969, was a member of the group of graduate students who connected the first computer to a "switch," another computer that would serve to route data from one host computer to another.

This was the first step in building the Advanced Research Projects Agency Network, ARPANET, which was the first packet-switched network and the forerunner of the Internet. By connecting the computer to the switch, the two computers could "talk," or network, with each other. Thus, on September, 2, 1969, Cerf, Kleinrock, and others succeeded in hooking their UNIX computer to a refrigerator-sized switch known as an Interface Message Processor (IMP). This successful test allowed the group to connect UCLA's computer to Stanford's on October 20, 1969. Although the system crashed on the first attempt, the first two nodes of ARPANET had been joined.

During his tenure at UCLA, Cerf met Bob Kahn, who was designing the hardware backbone for ARPANET. Kahn and Cerf worked together to measure the data flow through the fledgling network. After receiving his doctorate from UCLA, Cerf accepted a position as assistant professor at Stanford in 1972. While at Stanford, he began engaging in research on packet network interconnection protocols. He also began working with Kahn on the Department of Defense's ARPANET project. The pair were attempting to establish communication protocols for the fledgling network.

LIFE'S WORK

At its inception, ARPANET was more of an idea than an actual network of connected computers. The main problem was that each of the sites had different computers, each computer was the size of a refrigerator or larger, and each computer operated in its own specialized language. Because of this problem, the communication between computers had to be mediated by a third computer called an Interface Message Processor. The initial challenge that DARPA faced was to have IMP allow for packets of data, or "datagrams," that had been created on different machines through different computing languages to seamlessly flow from the point of origin to the intended destination without data loss or corruption.

The answer to this problem was a set of protocols that have come to be known as the Internet Protocol Suite. In 1969, Cerf led the way in writing the original transmission protocols for ARPANET, which were known first as Telnet (protocols that allowed remote log-ins) and by early 1970 as a complete set of protocols known as Network Control Protocols (NCPs). However, by 1972, Cerf and Kahn, who was hired by DARPA in 1972 to work on radio and satellite packet networks, realized that a new set of protocols were needed. Within a year, Cerf and Kahn had developed a new Internet Protocol (IP), in which any differences between sending and receiving networks were hidden behind the IP itself. This new approach meant that since the network was not responsible for the reliability of the data, the sending and receiving machines would have to find ways to ensure data validity.

In 1973, Cerf and Kahn presented a paper outlining their new protocols to the International Networking Group. By May, 1974, they published "A Protocol for Packet Network Intercommunication," which described the initial version of Transmission Control Protocol (TCP). By 1976, Cerf was hired away from Stanford to work as the program manager for packet radio, packet satellite, and other related research programs on the DARPA Internet. In October, 1977, the pair demonstrated a protocol that linked three separate networks—Packet Radio Net, ARPANET, and SATNET—to the University of Southern California's Information Sciences Institute. The packets of data were transmitted 94,000 miles with no loss of data. This was the first demonstration of the TCP aspect of the new protocols.

In 1978, Cerf and his colleagues continued refining the protocols by separating the IP from the TCP to create a multilayered protocol that was more reliable and stable than the original TCP had been. This approach reduced the problem of conflicts between networks and programming languages to a negligible issue.

The original protocol designs for NCP had envisioned connecting a total of just 256 network hosts. By March, 1982, the Department of Defense had made TCP/IP the standard protocol for all military networking. One year later, the final NCP-to-TCP/IP transition took place, and there were just a few hundred host computers on the network. Ten years later, thanks in part to Cerf's linking MCI Mail, the first commercial e-mail system, to the Internet, the number of hosts had grown to over 1.3 million.

Although TCP/IP undergoes continual evaluation and change through its "requests for comments" (RFC) pro-

Internet pioneer Vinton Gray Cerf, seen here in 1999, codeveloped TCP/IP, a suite of computer networking protocols that became the language of the Internet. (Getty Images)

TCP/IP

Transmission Control Protocol/Internet Protocol (TCP/IP) is a suite of protocols, or a common language, allowing for the management of the transmission of information between interconnected computers and interconnected networks. Using TCP/IP, the network, rather than the individual computers that make up the network, becomes responsible for routing the packets of data. Designed primarily by Vinton Gray Cerf and Bob Kahn, the TCP/IP suite was established to determine a specific format for each packet of data that would be transmitted across the network as well as the protocols that determined how those packets would travel to their destination and be reconstructed once they arrived.

Although the protocols are generally thought of as one unit, the TCP and the IP serve different functions in the transmission of data across a network. IP's primary task is the actual routing of the packets from their point of origin to their destination. This task is accomplished by addressing and forwarding the individual packets. To accomplish this, each "end host," or computer hooked up to the Internet, is assigned a distinctive IP address. The IP address is a 32-bit number (which may, due to the demand for IP addresses, become a 128-bit number in the future) that identifies the network, subnetwork, the host, and the specific machine to which a packet should be routed. By way of comparison, the packet is an envelope containing a chunk of the data being sent and the IP address is the mailing address of the intended recipient.

The packets themselves are chunks of bytes that are created when the original file—which can be a Web page, an image, a sound, or a video—is broken up into smaller pieces. Each packet is made up of a header, which contains the IP address and routing information, and the body, which is the TCP data. The TCP data will later be reassembled to re-create the original file.

IP's service, by itself, is unreliable—in that it only makes sure that the packets get to the address. IP does nothing to guarantee the accuracy or validity of the contents when they arrive. IP does not protect against data corruption, lost packets, packets arriving in the wrong order, or packets being duplicated en route. Ensuring reliability is the role of TCP, which guarantees reliable delivery of data by monitoring and controlling the packets as they flow through the network. Upon reassembly, the packets are checked for errors and put into the proper order; if necessary, a call is sent back to the host machine to resend any lost packets. Once TCP has re-created the original file, it sends that file to the application program that requested the file from the original host.

If everything is working properly, in less than a second TCP delivers the file an application has requested from a remote host halfway around the globe. TCP is utilized by the Internet's hottest applications, ranging from the World Wide Web and e-mail to streaming media and online gaming.

cedures, the protocols themselves have remained remarkably unchanged. Future versions may require larger bit sizes for IP addresses or may incorporate stronger algorithms for data correction or error detection, but the heart of the protocols continues to withstand scrutiny and deliver data quickly and efficiently.

IMPACT

Only rarely does an innovation lead to fundamental changes to the means by which entire populations communicate. TCP/IP was one of those innovations. By creating the protocols that allowed computers and networks to be linked together, Cerf, Kahn, and their colleagues opened the floodgates for the innovations that followed such as the World Wide Web, Web browsers, and search engines. The protocols that comprise TCP/IP serve as the rules of the road upon which the information highway was made navigable and colonized. The TCP/IP turned ARPANET into the Internet, as the NCP and other competing protocols simply were not capable of handling the sheer volume of traffic that occurred as ARPANET evolved into the Internet.

—B. Keith Murphy

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See also: Tim Berners-Lee; Robert Cailliau; Philip Emeagwali; Bob Kahn.

GEORGES CLAUDE

French chemist

Claude's development of the neon sign illuminated the commercial landscape in developed countries throughout the world. His signs enabled businesses to attract customers just as easily at night as during the day.

Born: September 24, 1870; Paris, France
Died: May 23, 1960; Saint-Cloud, France
Primary fields: Chemistry; electronics and electrical engineering
Primary invention: Neon lighting

EARLY LIFE

Georges Claude (zhawrzh klohd) was born into a middle-class family in Paris, France. His father was assistant director of the Manufactures des Glaces de Saint-Gobin. Claude attended the École de Physique et de Chimie Industrielles de Paris. While studying there, he was a student of biophysicist Jacques-Arsène d'Arsonval, who in 1881 proposed generating electric power by utilizing the temperature difference between the warm surface water of the ocean and the deep ocean water. D'Arsonval did not do any experiments to verify his theory, but he did give Claude an idea for later research. The process is now known as ocean thermal energy conversion (OTEC). Claude graduated in 1886 and obtained a position with the municipal electricity works of Paris. While working with a high-tension wire, he was involved in a near-fatal accident. This experience prompted him to develop improved safety measures.

LIFE'S WORK

In 1897, Claude made his first major contribution as an industrial chemist. He invented a means by which acetylene, an extremely dangerous flammable gas, could be transported at greatly reduced risk by dissolving it in acetone. His method resulted in an expansion of the acetylene industry. In 1902, he successfully developed a process for producing liquefied air in the large quantities for industrial use. His process, which he patented, employed separation by fractional distillation. That year, in partnership with businessman Paul Delorme, Claude established the corporation L'Air Liquide. Claude supplied liquid oxygen to the Scottish chemist Sir William Ramsay, known for his extensive research on inert gases, and Claude himself began studying such gases. In addition, he devised improved methods for generating power from the energy released by liquid oxygen when it is reconverted into gas. His method became known as the Claude cycle. As early as 1910, he advocated the use of liquid oxygen in iron smelting, but his idea found little support until after World War II.

Claude continued to study and experiment with inert gases. His experiments with neon led him to discover, in 1910, that a sealed tube filled with the gas emitted a bright red-orange light when electricity ran through it. He also developed a way to purify the neon in the tube by using a charcoal filter. Claude next invented the neon lamp, which he exhibited at the Paris Motor Show on December 11, 1910.

Claude elaborated his work on neon-filled tubes, bending them to form letters and pictures and combining these tubes to make signs. The first neon sign was displayed at a Paris barbershop in 1912. He obtained international patents on his invention and founded the Claude Neon Company. His nephew André Claude served as director of the company and later developed the fluorescent light. Georges Claude's neon signs quickly became popular in the advertising community. In 1923, he sold two signs to Earle C. Anthony, owner of the Packard car dealership in Los Angeles. The "Packard" signs were the first neon signs in the United States, where neon signage became a fixture of the culture. In 1929, the first neon sign appeared in Las Vegas, Nevada, at the Oasis Café. However, manufacturing the signs in France and shipping them to the United States proved to be unsatisfactory in terms of time and transport, so Claude sold the licensing rights for the manufacture of neon tubing in the United States to the Federal Sign and Signal Company of Chicago. In 1937, Claude entered into a franchise agreement that established Claude Neon in Johannesburg, South Africa. Neon signs were manufactured in various places around the world, and Claude became a very rich man.

During the time that Claude was experimenting and developing the neon lamp and neon sign, he was also doing research in other areas. Around the time of World War I, he discovered a method for producing liquid chlorine, used in poison gas. In 1917, basing his work on that of French chemist Henri Le Châtelier, Claude invented an economical process that used high pressure to synthesize ammonia. In 1924, he was elected to the Académie des Sciences.

In 1926, using concepts proposed by his former teacher D'Arsonval, Claude began investigating ocean thermal energy conversion. In Cuba in 1930, he built the first prototype plant employing the technology. Using a low-pressure turbine, he successfully produced 22 kilowatts of electricity. In 1935, he purchased a cargo ship, *La Tunisie*, which he anchored just off the coast of Brazil, aboard which he built another plant. However, both plants were destroyed by inclement weather and rough seas before they could prove Claude's project economical and practical.

During World War II, Claude served as scientific adviser to Marshall Philippe Pétain's Vichy government. At the end of the war, Claude was accused of collaboration with the Nazis and charged with helping to design the V-1 rocket. The latter charge was dropped. In 1945, he was sentenced to life in prison, expelled from the Académie des Sciences, and deprived of the honors he had received for his scientific work during World War I. His friends immediately began efforts to secure his release, which came in 1949. During the last years of his life, he returned to investigating OTEC. Claude died on May 24, 1960, in Saint-Cloud, France, at the age of eighty-nine.

IMPACT

Claude made important contributions in a variety of fields. His method of safely transporting acetylene by dissolving it in acetone enabled industries involved in operations such as chemical synthesis and welding to increase their use of the gas and thus improve their production. Claude's process for producing large quantities of liquid air made its use in industry practical. His research into ocean thermal energy conversion laid the groundwork for later investigation into this environmentally friendly technology. Claude's research into methods of making poisonous gases significantly changed warfare during World War I.

Claude's most important impact was, however, in the advertising industry. His invention of the neon light and its use in signs revolutionized advertising. His neon signs were

THE NEON SIGN

After supplying liquid oxygen to Scottish chemist Sir William Ramsay, Georges Claude became interested in studying inert gases. In 1910, he discovered that a sealed tube filled with neon produced a bright red-orange light when electric current ran through it. Following his discovery, Claude invented a neon lamp. He then discovered how to bend the tubes and form letters, which became neon signs.

Hollow glass tubes are used for making neon signs. Lead glass tubes are the type most commonly used. They usually have a diameter ranging from eight to fifteen millimeters. Lengths of the tubes vary. The tubes are scored with a file before they are heated; this enables the glass bender to snap or break them at the desired lengths after they have been heated. The tubes are then heated in sections until they become malleable and can be bent into the desired shapes. Next, they are lined up with a graphics or lettering pattern to be used for the sign.

Once a tube is finished, an electrode is welded to each end. These electrodes are made of lead glass and have a metal shell. Two wires extend beyond the electrode so that the sign wiring can be attached later. It is extremely important that all of the welds and seals are secure without any leaks.

The finished tubes are then processed. First, each tube is attached to a manifold attached to a vacuum pump. The tube is evacuated of air until it reaches near-vacuum. While this process occurs, a high current of electric charge is forced through the tube by way of the wires protruding from the electrodes. This process, known as bombarding, heats the glass tube to a temperature of several hundred degrees Celsius, producing a very clean interior of the glass tube at a high vacuum. The tube is left attached to the manifold and allowed to cool. It is then filled with neon, argon, or a mixture of gases.

Claude's neon signs brought a new energy to the commercial districts of cities and even to residential neighborhoods, where local shops displayed these blazing, attention-grabbing signs. Light and color became essentials of outdoor advertising.

bright and attractive; they made the old painted signs appear dreary and obsolete. Neon signs appeared outside of car dealerships, restaurants, movie theaters, and almost every type of establishment imaginable. Undoubtedly, the neon sign played an extremely important role in the development of the entertainment industry in Las Vegas.

—*Shawncey Webb*

Further Reading

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Davidson, Len. *Vintage Neon*. Atglen, Pa.: Schiffer, 1999. Authored by the founder of the Neon Museum of Philadelphia, the book includes photographs with commentary by shopkeepers, manufacturers, and others involved with neon signs. Offers a good panoramic view for understanding how Claude's invention of the neon sign changed the landscape of America, lighting it with bright cowboys, cars, bowling pins, and other figures.

Miller, Samuel. *Neon Techniques*. Edited by Wayne Strattman. Cincinnati: ST Media Group International, 1997. First published in 1935, the book gives detailed descriptions and explanations of design and fabrication of neon signs. Discusses techniques of bending and filling tubes. Explains various means of producing electrical discharge. Somewhat technical but clear.

Takahashi, Masayuki Mac. *Deep Ocean Water as Our Next Natural Resource*. Translated by Kazuhiro Kitazawa and Paul Snowden. Tokyo: Terra Scientific, 2000. Recounts details of the plants Claude constructed and the methods he applied to produce electricity. Discusses why his project met with failure.

See also: Fritz Haber; Dimitry Ivanovich Mendeleyev.

Josephine Garis Cochran

American engineer

Cochran patented the dishwasher that provided the basic design for the modern dishwasher. She also opened her own manufacturing facility, Cochran's Crescent Washing Machine Company, which later became KitchenAid.

Born: March 8, 1839; Ashtabula County, Ohio
Died: August 3, 1913; Chicago, Illinois
Also known as: Josephine Garis (birth name); Josephine M. Fitch
Primary field: Household products
Primary invention: Dishwasher

Early Life

Josephine Garis Cochran (KAHK-rehn) was born to Irene Fitch and John Garis in the spring of 1839 in Ashtabula County, Ohio (some sources say Valparaiso, Indiana). Her family involvement with engineering was influential to her education when she was young. Her maternal grandfather (possibly her great-grandfather), John Fitch, patented what is reportedly the first steamboat in 1791. Her father served as an engineer consultant who worked in both Ohio and Indiana supervising saw and textile mills along the Ohio River. He took the young Josephine with him during some of his travels, influencing her views of manufacturing facilities and engineering. John Garis is also credited with inventing a hydraulic pump system that drained marshes, an invention that probably led to a later consulting job on the building of Chicago in the 1850's.

When Josephine's private Indiana high school burned down, she moved to central Illinois to live with a sister. There, she met William A. Cochran, a local civil servant, and married him on October 13, 1858, at the age of nineteen. Reports say that she added an *e* to "Cochran" after his death in 1883. They had one child, a son named Hallie, who died at the age of two. The Cochrans were founding members of the First Congregational Church in Shelbyville, Indiana. During the last years of his life, William Cochran was ill and in debt—factors that contributed to Josephine Garis Cochran's push to finish her invention, the dishwasher.

Life's Work

Cochran's decision to invent a dishwashing machine was reportedly influenced by her irritation with the way her servants were handling her heirloom china. Observing chips and breaks in dishes that had been passed down since the 1600's, she began washing the dishes herself. Since she detested this job, she decided to invent a ma-

THE DISHWASHER

Josephine Garis Cochran's lack of formal mechanical training may have been a problem for some, but her technological acumen was strong enough to make her into a brilliant businesswoman who threw aside expectations for women in her time to become the inventor of the forerunner of the modern dishwasher. Her experiments with water pressure washing of dishes to preserve her time and her china led to her invention. Her innovations included racks that were moved manually and, later, mechanically, racks that moved back and forth, and racks that revolved. In early models, hand-pumped water was poured over dishes held in stationary racks. Later models were motorized, spraying hot water and soap onto moving racks. Before her invention, it was thought that mechanized scrubbing was the only way to effectively clean the dishes.

The Garis-Cochran Dish-Washing Machine worked so well that it sold in large quantities to hotels and restaurants across the United States, with the inventor herself traveling to cities such as St. Louis, Cleveland, and New York to sell her product. Her salesmanship was direct and bold, earning her a strong business reputation. Though her early dishwashing models were too large and expensive for general home use, Cochran invented a smaller model that would work in the home, and she creatively marketed it as a place to hide dirty dishware, appealing to a large number of homemakers (though the average home would not be able to afford one for decades).

As she built her business, Cochran and her machine became linked to several manufacturing companies. Her own factory, Cochran's Crescent Washing Machine Company, was invested in by Tait Manufacturing in Decatur, Illinois. The investments allowed her to make renovations to her machine, leading to a second patent in 1900. Her company was purchased by Hobart in 1926 and was later turned over to KitchenAid, which was acquired by Whirlpool Corporation in 1986.

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chine to do the work for her. Testing ideas for the machine, she streamed water over the dishes in the sink to see how clean the dishes would become.

As her idea progressed, she turned the woodshed behind her house into a workshop. George Butters, a mechanic for the Illinois Central Railroad, became her assistant in the design and building of her project. One of her goals in designing the early dishwashing machine was to avoid power-driven, motorized brushing of the dishes. They started with a washtub construction that would contain the dishes and keep the soap and water from spraying all over the kitchen. As a result, a copper boiler became the central piece to the new machine. The boiler was built into a large frame, and racks were placed inside to hold the dishes. Reports vary on whether the racks were made of wood or wire, with wire being the predominantly accepted material, at least for the later models. The early model, made with wooden racks, worked with a hand pump that sprayed hot water and soap against the dishes that were set into the individual racks.

Cochran applied for a patent and was awarded one on December 28, 1886. Her machine was officially called the Garis-Cochran Dishwasher (also known as the Garis-Cochran Dish-Washing Machine). The idea of a dishwashing machine was not new; a hand-cranked wooden machine had been patented by Joel Houghton in 1850. Other inventors had applied for patents as well, but whereas their models were based on the motorized scrubbing of the dishes, Cochran's used a water pressure wash.

Cochran's first models after the patent were manufactured by local machine shops and sold for between $100 and $150 apiece. The size and price were prohibitive to home owners, so Cochran sold them to hotels and institutions. Her first sale was to the Palmer House, a prestigious Chicago hotel. She later sold to the Sherman House, another upscale Chicago hotel, as well as other large businesses. The dishwashing machine was under almost constant revision; Cochran worked to make it more efficient and more marketable. To reach the home market, she advertised the dishwasher as a good place to store dirty dishes, hiding them from sight. Then, in 1888, she sold a machine that reportedly was able to wash 120 dishes per minute.

In 1889, Cochran opened her own manufacturing facility, which she called Cochran's Crescent Washing Machine Company. Her early assistant, George Butters, became the foreman, and three other employees were hired to build the commercial washers. The company made several models and sizes. One model held dirty dishes in racks that were placed inside a boxlike container where hot soapy water was hand-pumped over the dishes. The operator would need to pour clean hot water afterward to rinse them. A motorized version was also manufactured. In this machine, dishes were placed in racks that moved back and forth while water sprayed up from underneath. This version was easy enough to operate by anyone. A motor was made to be connected to the side, but this required an extra purchase.

At the 1893 World's Columbian Exposition (World's Fair) held in Chicago, Cochran made her real break into sales. While displaying her machine and marketing it herself, she loaned nine dishwashers to other businesses at the exposition. The approval was overwhelming, and she sold the same number of machines. This began her busiest time in the business.

Over the next decades, the Garis-Cochran Dishwasher evolved several times. In 1900, Cochran registered for a patent on the new model that moved dishes back and forth. There was also a version that rotated the racks of dishes and then drained into a sink. Cochran herself became quite a businesswoman, traveling around the country selling her machines. It is reported that she even traveled into her seventies. She died in 1913 at the age of seventy-four.

Impact

The Garis-Cochran Dish-Washing Machine is the forerunner of the modern dishwasher. The pressure washing system that utilized hot water, soap, and air drying kept dishes from being damaged in the washing process. Cochran's innovation took off at the 1893 World's Columbian Exposition, leading to many imitations of her machine, none of which were as good. Cochran spent the middle and later years of her life inventing, building, and selling her dishwasher to institutions that could afford and house it. Her machine was so efficient that it replaced up to three-quarters of the kitchen staff in larger restaurants and hotels.

Though lacking technical training, Cochran was an innovative woman who took a chance on building a dishwashing machine. She boldly sold her invention, going on cold calls to businesses herself and modeling it herself at the 1893 World's Fair.

Cochran wanted to build a machine that would lessen the household workload of women, and this dream became a widespread reality after her death. By the 1940's, Cochran's idea had been downsized to a dishwasher that would become popular in the home. A version of this dishwasher is still manufactured and used today.

—Theresa L. Stowell

Further Reading

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Fenster, J. M. "The Woman Who Invented the Dishwasher." *American Heritage of Invention and Technology* 15, no. 2 (1999): 54-61. Provides a strong overview of Cochran's life and invention. Fenster provides a detailed tracing of her life, including information on her parents and husband and their influence on her. The article also includes information on her manufacturing and sales processes.

Karwatka, Dennis. "Josephine Cochrane Invents the First Practical Dishwasher." *Tech Directions* 59, no. 10 (2000): 12. Karwatka provides a brief but thorough description of Cochran's dishwasher and how it worked. He also includes a copy of an 1895 advertisement for the machine that provides interesting, pertinent details about the machine.

Vare, Ethlie Ann, and Greg Ptacek. *Patently Female*. New York: Wiley, 2002. Starting with the first patent ever awarded to a woman, this book traces largely unknown female inventors. For some female inventors, the authors provide a connection to famous male figures who may have taken or received credit for the women's concepts and works. The authors do not always provide specific dates.

See also: Beulah Louise Henry; James Murray Spangler; Percy L. Spencer; Earl S. Tupper.

SIR CHRISTOPHER COCKERELL

English engineer

Cockerell became world famous for his invention of the hovercraft, but he had earlier made a highly significant contribution to the British war effort in World War II, developing radio communication and navigation devices for use in the Royal Air Force and the Fleet Air Arm. He also made some notable early contributions to the development of prewar television technology.

Born: June 4, 1910; Cambridge, England
Died: June 1, 1999; Sutton Scotney, Hampshire, England
Primary fields: Aeronautics and aerospace technology; mechanical engineering; navigation
Primary invention: Hovercraft

EARLY LIFE

Christopher Sydney Cockerell was the only son among the three children of Sir Sydney Carlyle Cockerell (1867-1962), the director of the Fitzwilliam Museum in Cambridge, England, and his wife, Florence Kate (1872-1949). Christopher never got on with his father, who had once been William Morris's secretary and to whom his son's interest in the practicalities of engineering always seemed vulgar. Christopher had a much better relationship with his mother, a talented artist and illuminator. His father's literary interests were reflected in the visitors to the family home, who included George Bernard Shaw, Joseph Conrad, Siegfried Sassoon and T. E. Lawrence, but the only conspicuous interest that Christopher showed in these worthies was in Lawrence's motorcycle. A succession of governesses hired to teach him at home despaired of diverting his interests into more "acceptable" channels; he became passionately interested in radio, building his own TV set, and built a steam engine to power his mother's sewing machine—which she refused to use.

After attending Lydgate House Preparatory School in Hunstanton for three years (1921-1924)—where he built a radio set for the school—he went on to Gresham's School in Holt, where he met W. H. Auden and built another radio. Cockerell went on to study engineering at Peterhouse College, Cambridge, spending much of his spare time working on motorbikes, winning several prizes for racing. He often stayed during vacations with Captain Edward George Spencer-Churchill, from whom he picked up a fascination with antiques and shooting. His father was disgusted when the young man spent the £20 he was given for his twenty-first birthday on a Mauser rifle with a telescopic sight and silencer.

LIFE'S WORK

After graduating from Cambridge, Cockerell initially went to work for W. H. Allen and Sons of Bedford as a pupil engineer, but he soon returned to Cambridge to do research on radio and electronics. In 1935, he joined the Marconi Wireless Telegraph Company, working at the company's Writtle site near Chelmsford. He worked on the first outside broadcast vehicle used by the British Broadcasting Corporation (BBC), and he helped develop the shortwave aerials that began transmitting TV signals from Alexandra Palace. In 1937, however, his career took a crucial turn when he was promoted to head of Aircraft Research and Development. On September 4 of that year, he married Margaret Elinor Belsham.

Cockerell's last prewar commission for Marconi was to develop a radio direction-finder for the Cunard liner *Mauretania*. When war broke out, he was immediately approached to develop similar equipment for use in aircraft. Great Britain's bombers were in dire need of better communication and navigation equipment, and Cockerell immediately came up with a prototype system that was rushed into production in a matter of weeks. The system proved invaluable in helping bombers make their way home after raids, and it made a vital contribution to the conflict between the Royal Air Force (RAF) and Germany's Luftwaffe, in which the RAF's initial disadvantage was eventually reversed.

With the assistance of the firm of E. K. Cole, Marconi manufactured some 120,000 R1155 receiver units and some 55,000 T1554 transmitters during the war; Cockerell always regarded this as the most important achievement of his career. He also helped produce a universal display unit for the Royal Navy that integrated radar information with other instrumentation, and he developed a beacon that allowed Fleet Air Arm pilots to return safely to their carriers. In the run-up to D Day, he developed an apparatus, code-named "Bagful," that allowed the RAF to locate and map all the German radar stations in northern France.

When the war was over, Cockerell continued to work on equipment for both military and civil aircraft, developing improved navigation systems and apparatuses for positioning aircraft during their final approach to landing. He refused further promotions because he wanted to

Hovercraft inventor Sir Christopher Cockerell, center, with pilot Peter Lamb, left, and Saunders Roe designer Richard Stanton-Jones with an early model of the SR-N1 hovercraft in 1959. (Popperfoto/Getty Images)

maintain the level of his practical involvement. In 1948, he moved to the Marconi research laboratories at Great Baddow, near Chelmsford, but resigned in 1951 because he wanted to be able to follow up his own initiatives more freely. His wife's inheritance from her father had been invested in a boat-building business at Oulton Broad, near Lowestoft, and Cockerell went to work for the company designing motorboats. He soon became interested in the possibility of minimizing the resistance of the water to a boat's progress by floating the vehicle on a cushion of air. In December, 1955, he filed a patent for his hovercraft design.

Cockerell could not get industrial backing to develop the hovercraft, and the Admiralty was not impressed either, although the Ministry of Supply was instructed to put it on the secret list. Saunders Roe, on the Isle of Wight, undertook to build a prototype for the ministry and reported favorably on its progress in 1958, at which point the company was commissioned to build a much larger 400-ton model for potential use as a cross-channel ferry. It proved impossible to maintain secrecy, and the project was declassified. The National Research and Development Corporation (NRDC) then provided financial support, forming a subsidiary company, Hovercraft Development Ltd., in January of 1959. Although the company's offices were initially located in Cockerell's home in East Cowes, Cockerell was merely a director and technical consultant, while the chairman and managing director was the NRDC's Dennis Hennessy. When the company moved across Southampton Water to Hythe in 1960, Cockerell bought a house there, where he lived for the rest of his life.

The Saunders Roe model SR-N1 was shown to the press on June 11, 1959, causing something of a sensation.

On July 25, it made a channel crossing, fifty years to the day after Louis Blériot's first aerial crossing. An experimental track for hover trains was set up near Cambridge. Hovercraft Development eventually filed some two hundred patents, fifty-nine of them in Cockerell's name. Licences to build hovercraft were granted to various companies, including Saunders Roe, Vickers, Folland, and Cushion Craft in the United Kingdom; Bell Aircraft in the United States; and Mitsui and Mitsubishi in Japan. The various British enterprises were soon merged into the British Hovercraft Corporation—a move strenuously opposed by Cockerell, who believed (correctly, as it turned out) that the merger would stifle innovation. He resigned from the new entity on March 23, 1966. He was knighted in 1969 for his contributions to engineering.

In the 1970's, Cockerell became very interested in the possibility of developing technologies of renewable energy that would outlast intrinsically limited supplies of coal and oil. He and Edwin Gifford, with whom he had previously worked on hovercraft development, formed a company called Wavepower Ltd. to exploit a number of patents that Cockerell took out for devices to produce electricity from the energy of waves. The prototypes worked, but the electricity they produced was far more expensive than conventionally generated electricity, and the company had to be wound up in 1982.

By this time, Cockerell was in his seventies, and he was unable to initiate a further phase of his remarkable career, but he remained very active as a public figure, firing off scores of letters to the press and various institutions, frequently complaining about the low status of engineers in British society and the fact that the British education system was turning out "half-educated people" with no appreciation of science and technology. He died in 1999 in Sutton Manor Nursing Home in Hampshire and was survived by his two daughters, Anne and Frances.

IMPACT

Cockerell became famous as the archetypal British inventor of the twentieth century, and the hovercraft became—somewhat ironically, as things turned out—a key example of British technological ingenuity. The hovercraft failed to live up to his hopes, at least in the fact that its development was far more successful outside Britain than within, and proved to be of peripheral value in a relatively limited range of contexts.

THE HOVERCRAFT

While working for a motorboat company, Christopher Cockerell began to consider the possibility of reducing the friction between the water and a boat by floating the vehicle on a cushion of air. This idea led him to invent the hovercraft, an amphibious vehicle that can hover above both water and land. The hovercraft's large fan directs air under the vehicle, inflating the flexible "skirt" and generating lift. The skirt not only prevents air from escaping but also allows the vehicle to clear obstacles. A proportion of fan-generated air is expelled at the back of the craft to generate thrust.

On December 12, 1955, Cockerell filed for his first hovercraft patent. Various earlier attempts had been made to build a hovercraft before his success. He was almost beaten to it by Colonel Melville W. Beardsley, who built a prototype for the U.S. Navy in 1959 and to whom Hovercraft Development Ltd. had to pay a large sum for his U.S. patents. The SR-N1 model, demonstrated in the same year, was initially impractical because its hovering height of one foot caused problems when the waves were higher than two feet. The machine only became viable when it was fitted with a flexible skirt, devised by Denys Bliss. The skirt, made of nylon-reinforced rubber, enabled the hovercraft to cope with considerably higher seas.

The first passenger-carrying hovercraft was the Vickers VA-3, which operated along the North Ales coast. Cockerell, Edwin Gifford, and Don Robertson formed Hovertransport Ltd. in 1964 to operate a ferry across the Solent, between Southsea in Hampshire and Ryde in the Isle of Wight, but British Rail decided to buy the first craft—the SR-N4—for use as a cross-channel ferry. Six of them were built for that purpose, four of which were widened and two lengthened as well. The last two, which could carry sixty cars and more than four hundred passengers, continued to operate as cross-channel ferries until they were decommissioned in October, 2000, being unable to withstand competition from the Channel Tunnel and fast catamarans known as SeaCats. The SR-N6 went into service between Southsea and Ryde, carrying thirty-six passengers, and that route was still in use in the twenty-first century, operated by two 98-seater AP1-88s.

The hovercraft was more ingeniously exploited by the U.S. Navy, which retained its interest in its potential after Beardsley's work was superseded and Bell Aircraft began producing the craft under license from Saunders Roe. Hovercraft operated successfully in the Mekong Delta during the Vietnam War and were used as tank-landing craft in the Gulf War. Interest was also maintained in Japan, where a hovertrain was installed at Narita International Airport.

Cockerell was quite right to regard his war work as the greatest achievement of his career. He played no small part in saving Britain from an invasion by air that would have changed the history of the twentieth century dramatically had Nazi Germany succeeded, and he also made a key contribution to facilitating the counterinvasion of northern France that eventually brought the war in Europe to an end. Of all the many inventors and engineers who played a part in the war effort, there was probably none whose summary contribution was more important than Cockerell's.

—Brian Stableford

FURTHER READING

Johnson, P. S. *The Economics of Invention and Innovation: With a Case Study of the Development of the Hovercraft*. London: M. Robertson, 1975. An interesting analysis of the difficulties of exploiting Cockerell's key invention.

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_______. "Sir Christopher Sydney Cockerell CBE, RDI, 4 June 1910-1 June 1999." *Biographical Memoirs of Fellows of the Royal Society* 47 (November, 2001): 69-89. A more leisurely biography than the same author's entry for the *Oxford Dictionary of National Biography*. Covers the same ground in slightly more detail.

See also: Sir Robert Alexander Watson-Watt; Sir Frank Whittle.

STANLEY NORMAN COHEN

American geneticist

Cohen, along with Herbert Wayne Boyer, was the first scientist to create a functional recombinant DNA molecule. This signal achievement forms the bedrock of modern genetic engineering and gave rise to the multibillion-dollar field of biotechnology.

Born: February 17, 1935; Perth Amboy, New Jersey
Primary fields: Biology; genetics
Primary invention: First recombinant DNA organism

EARLY LIFE

Stanley Norman Cohen was born in Perth Amboy, New Jersey, just across Arthur Kill from the southern tip of Staten Island, New York. He attended Rutgers University, graduating in 1956 with a bachelor of science degree in biological sciences. In 1960, he earned his medical degree from the University of Pennsylvania School of Medicine. Following postdoctoral work, Cohen joined the faculty at the Stanford University School of Medicine in 1968, where he held teaching and research positions as a professor of genetics and medicine.

By 1972, Cohen had begun work on the problem of antibiotic resistance in bacteria. Several genes coding for such resistance had previously been found on bacterial plasmids. Plasmids are small, extrachromosomal, circular bits of DNA with the capacity to be passed, intact, between different bacteria. In other words, the plasmids and their genes are mobile. Bacteria without antibiotic resistance could, under certain conditions, become resistant simply by picking up a resistance plasmid from another resistant bacterium. Although there are different mechanisms that confer resistance in bacteria, researchers had deduced that the genes for these mechanisms seemed to be passed in the same manner on plasmids. Cohen was interested in isolating these resistance genes so that he could insert them into *Escherichia coli* (*E. coli*), a common, well-characterized intestinal bacterium, and so further study the mechanisms of transmission.

At about this time in the late 1960's and early 1970's, several other research groups were working on the isolation and description of a group of enzymes called restriction enzymes. Herbert Wayne Boyer, from the University of California, San Francisco, was one such researcher working on restriction enzymes. These enzymes have the ability to recognize specific, short sequences of DNA and cut them, leaving either sheared off "blunt ends" or staggered "sticky ends." These ends of DNA can be matched up to complementary ends of different pieces of DNA and "glued" back together by another enzyme called DNA ligase. Most scientists in the field recognized that such enzymes could be a very valuable tool for dissecting various DNAs and studying them.

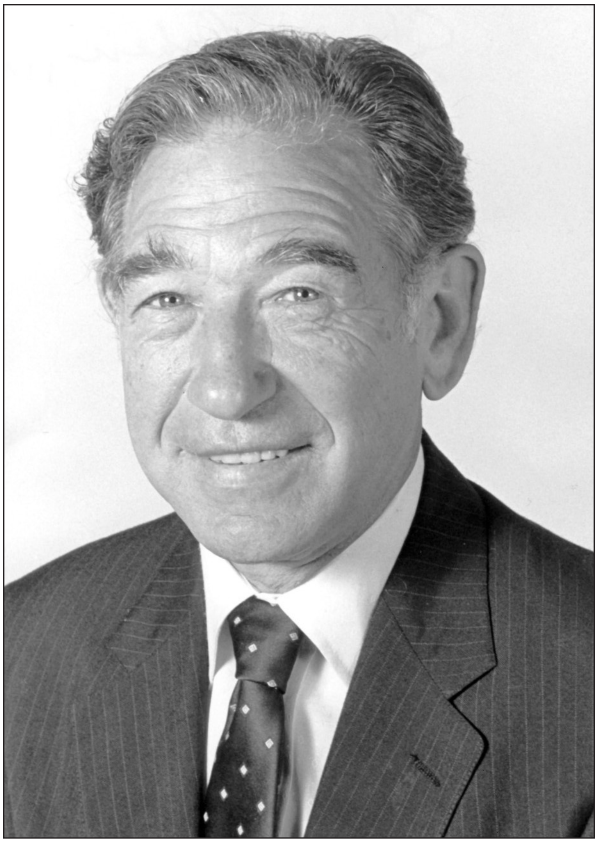
Cohen and Boyer met at a research conference in

1972 and discussed their work. From this discussion rose a collaboration that forever altered the fields of biological and medical research.

LIFE'S WORK

In order to understand how genes and their protein products work, it is generally necessary to isolate those genes away from the original systems in which they are found. Though this sounds reasonably simple today, this was a major hurdle facing Cohen and most researchers in the early 1970's. The key was to first isolate one gene from many and then graft it into a known and reasonably controlled biological environment that would allow predictable manipulation of that gene. Researchers were looking for a practical solution to a very real problem, and this is what the collaboration between Cohen and Boyer delivered.

Three things were needed in order to make a system that would be useful for further work in genetics. First, a way had to be found to get a specific piece of DNA into a living organism; in other words, scientists had to find a way to make recombinant DNA. Next, that DNA had to be made to replicate, or copy, itself in order to generate large amounts of the desired product. Finally, researchers had to be able to determine which cells received DNA (and so were "transformed" by that new DNA) and which cells did not; researchers had to "mark" the cells in some way so that the cells could be "selected." With Boyer's restriction enzymes and Cohen's work on plasmids, they succeeded in creating the first recombinant plasmid (pSC101), using it to transform *E. coli* cells in the presence of simple salts that facilitated plasmid transfer. Antibiotic resistance itself was used as a marker for selection. At its simplest, this system is the basis for all genetic engineering performed in the research laboratory today. The greatest utility of the system is that DNA from any organism, from human to mouse to corn, can be inserted into a bacterial plasmid for further study.



Stanley Norman Cohen. (©The Nobel Foundation)

Even before Cohen and Boyer published their collaborative work, Boyer presented the preliminary findings at the Gordon Conference on Nucleic Acids in June of 1973. The news was well received, but before the conference was even over some had expressed concerns about the safety of creating functional recombinant molecules, particularly if these novel genetic elements were then inserted into such an easily grown organism as a bacterium. From its inception, then, genetic engineering has had to weigh the merits of utility against the dangers of ill use. In the early 1970's, little was known about what, if any, dangers recombinant molecules might hold, and the issue split the scientific community. Cohen and Boyer were among the first cosigners of letters calling for a voluntary moratorium on certain types of research, at least until more was known. Other scientists scoffed at the perceived danger. Within a few short years, in 1975 the National Institutes of Health (NIH) formed the Recombinant DNA Advisory Committee (RAC) to include both scientists and the public in the debate. By 1976, the NIH had issued the *Recombinant DNA Research Guidelines*, which continue to guide research practices to this day. The *Guidelines* ensure that dangerous genetic combinations are restricted to laboratories to prevent them from "escaping" into nature, but as technological abilities have grown, new controversies continue to arise. Many modern ethical arguments focus not on *doing* genetic research but rather on the *applications* of it. Human cloning, even only of tissues, is probably one of the most hotly debated of the technologies to have come from Cohen and Boyer's original work.

Today, Cohen continues his work on the genetics of antibiotic resistance. His other research interests include

RNA decay and the growth of mammalian cells. Recently, work in the Cohen laboratory has produced GABRIEL, a bioinformatics program used in the analysis of DNA microarrays, which can be used to investigate the expression of thousands of genes at the same time.

Cohen has earned many awards over the years for his work in the field of genetics, including the Wolf Prize in Medicine in 1981 and the National Medal of Science in 1988. Along with Boyer, Cohen has won the National Medal of Technology (1989), the Lemelson-MIT Prize (1996), and the Shaw Prize in Life Science and Medicine (2004). Cohen was elected to the National Academy of Sciences in 1979 and was inducted into the Inventors Hall of Fame in 2001.

IMPACT

The collaborative work of Cohen and Boyer laid the foundations for genetic engineering, and as such their work comes next in importance only to the discovery of the structure of DNA itself by James D. Watson and Francis Crick. Cohen and Boyer's relatively simple method for creating and expressing recombinant DNA molecules in bacterial host cells spawned an expansion of research opportunities at university and governmental levels and launched the biotechnology industry. Their patents alone generated millions in royalties, and subsequent patents in biotechnology based on their work have generated billions. Boyer himself went on to cofound Genentech, one of the largest biotechnology companies in the world and the original creator of the first human insulin ever produced from recombinant DNA.

Genetic engineering finds applications in almost all scientific disciplines. Many modern medicines are produced from genetically modified bacteria. Many plants and some animals have also been modified to produce genetically modified foods or plants resistant to disease. Recombinant organisms are used to produce numerous industrial chemicals, dyes, biofuels, and synthetic materials. Engineered plasmids allowed a global collaboration on the mapping of the human genome and the genomes of many other living organisms. Detection of genetic diseases, cleaning up oil spills, and gene therapy for the curing of diseases also owe their success to the methods of Cohen and Boyer. It is not outrageous to claim that without their work, most modern biological and medical research could not take place.

—*Elizabeth A. Machunis-Masuoka*

RECOMBINANT PLASMIDS

In 1979, Stanley Norman Cohen and Herbert Wayne Boyer filed for and received the U.S. patent for the "Process for Producing Biologically Functional Molecular Chimeras." The patent explains how the two men and their coworkers created functional recombinant molecules that produced a novel product they wanted.

Plasmids are small, extrachromosomal, circular deoxyribonucleic acid (DNA) molecules that are found in many bacteria and that are capable of self-replication (copying). Intact genes put into these plasmids will be copied and expressed just as any other "natural" gene found on the plasmid. To produce a recombinant plasmid according to the methods developed by Cohen and Boyer, one first takes the chosen gene and removes it from whatever DNA strand it inhabits by cutting it out with a restriction enzyme (typically a restriction enzyme that creates "sticky ends"). Then, the bacterial plasmid is treated with the same restriction enzyme. The two DNAs are mixed together and DNA ligase is added. The sticky ends match up, and the ligase "patches" the strands together to reconstitute a complete plasmid, only now the plasmid is a recombinant. Host cells, such as *Escherichia coli* (*E. coli*), when exposed to calcium chloride (a simple salt), become more permeable to molecules outside their cell walls. When these salt-treated cells are mixed with DNA under the correct conditions, the DNA enters the cells. Once the cells have recovered from this transformation procedure, they begin to manufacture the protein products specified by the recombinant plasmid. To separate these bacterial "factories" from bacteria that did not take up recombinant DNA during transformation, some sort of selection mechanism is used. In Cohen's system, the recombinant plasmids all carry an antibiotic resistance gene, such as that coding for tetracycline resistance. After transformation, exposure to tetracycline in the growth media will kill off all cells that did not take up recombinant DNA. In this way, only the correctly transformed cells are kept, grown, and their recombinant products recovered.

This technique allows a researcher to express the product for any gene he or she cares to study. Insertion of the gene for human insulin into a bacterial plasmid allowed Genentech, the company founded by Boyer, to mass-produce human insulin for the treatment of diabetes. Engineered human insulin works better in patients than animal-produced insulin, thus providing better treatment outcomes for patients. Human insulin was only the first of a long list of synthetic medicines produced by recombinant DNA technology.

FURTHER READING

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Cohen, Stanley N., Annie C. Y. Chang, Herbert W. Boyer, and Robert B. Helling. "Construction of Biologically Functional Bacterial Plasmids *In Vitro*." *Proceedings of the National Academy of Sciences of the United States of America* 70, no. 11 (November, 1973): 3240-3244. Describes the critical first steps in the use of restriction enzymes for the creation of the first-ever recombinant DNA molecule.

Espejo, Roman, ed. *Biomedical Ethics: Opposing Viewpoints*. Opposing Viewpoints Series. San Diego, Calif.: Greenhaven Press, 2003. Genetic engineering and biotechnology have generated as much controversy as utility since the first plasmids were generated in the 1970's. This book gives both pro and con arguments for many of the applications of Cohen's original work as they apply to medical technologies such as human cloning and genetic research. Periodical and book bibliographies, discussion questions, and contact information for various bioethical organizations.

Fumento, Michael. *Bioevolution: How Biotechnology Is Changing Our World*. San Francisco, Calif.: Encounter Books, 2003. It is almost impossible to catalog all the ways in which biotechnology affects modern life, but this book provides a good starting point, ranging from "Miracles in Medicine" to "Biotech Brooms." Techniques and ethical issues are clearly presented. Endnotes with bibliographic information.

Krimsky, Sheldon. *Genetic Alchemy: The Social History of the Recombinant DNA Controversy*. Cambridge, Mass.: MIT Press. 1982. Provides an excellent chronology of the key events and primary documents of the initial controversies arising from the work of Cohen and Boyer. Extensive endnotes and bibliographic information.

See also: Herbert Wayne Boyer; Kary B. Mullis.

SAMUEL COLT

American industrialist and manufacturer

Colt created the mass-produced revolver, the first practical multishot firearm. The revolver was easy to carry for self-defense and was used as a weapon during the nineteenth century Indian wars.

Born: July 19, 1814; Hartford, Connecticut
Died: January 10, 1862; Hartford, Connecticut
Also known as: Colonel Colt
Primary fields: Manufacturing; military technology and weaponry
Primary invention: Colt revolver

EARLY LIFE

As a child, Samuel Colt's prized possession was an old cavalry pistol, which he taught himself to repair. His mother, Lucretia, died when he was six. His father, Christopher, remarried in 1823, and within a year the stepmother had sent Samuel to work on a farm. After a year on the farm, he moved to Ware, Massachusetts, to work in the new dyeing and milling factory his father had built, one of the first in the United States.

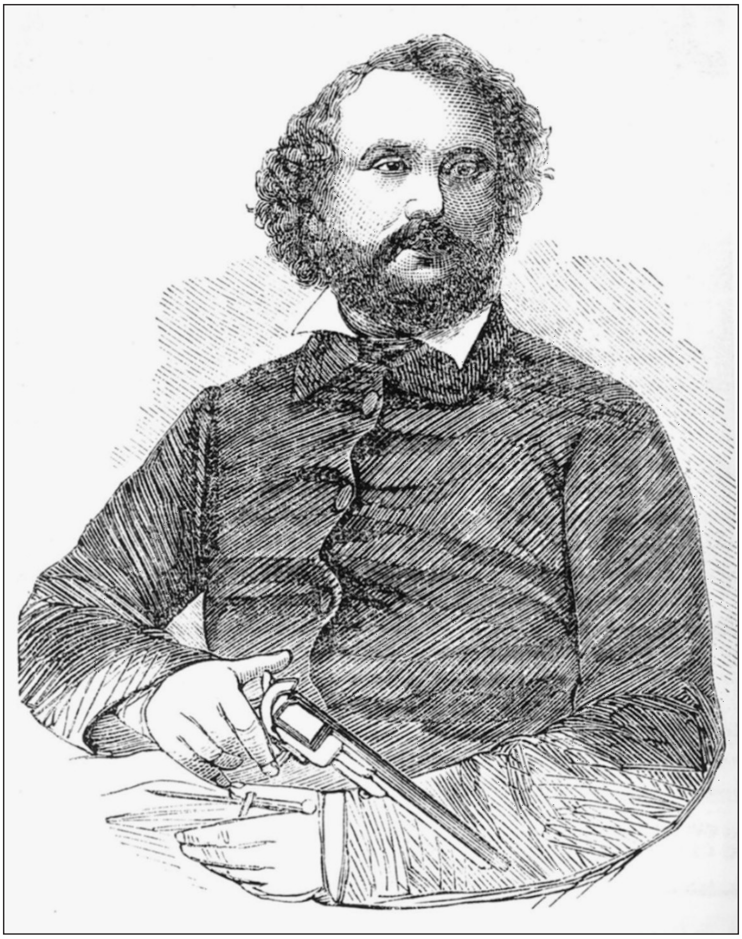
For a while, Samuel attended Amherst Academy, a boarding school in Massachusetts. He withdrew from the school after he fired a cannon in defiance of a teacher's order. The sixteen-year-old then set to sea, serving as a cabin boy on the brig *Corvo*, which visited Calcutta and London. According to legend, he observed the ship's wheel, saw how it could be locked into place, and decided that a similar locking mechanism could be used on a revolver firearm.

Upon his return to America, he began raising funds for the revolver project. He traveled the country as the "celebrated Doctor Coult of New York, London, and Calcutta," putting on exhibitions where spectators could consume "exhilarating gas" (nitrous oxide). He worked with thirteen gunsmiths or gunmakers to construct exemplars of the designs he had imagined. In 1835, at age twenty-one, he traveled to England to obtain a British patent for his revolver and obtained parallel French and American patents shortly thereafter.

Life's Work

Colt set up the Patent Arms Manufacturing Company in Paterson, New Jersey. The factory made revolving handguns, rifles, carbines (short rifles), and shotguns. Its first product was a small .34-caliber five-shooter pistol, produced in 1837. In 1838, Major General Thomas Jessup ordered fifty Colt revolver rifles for use in the ongoing Second Seminole War in Florida. Years later, General William Harney wrote that the Colts had been the decisive reason for the U.S. victory.

Colt firearms were popular with the military of the newly independent Republic of Texas, and in 1841 Colt finally obtained orders from the U.S. Army and Navy. However, overall sales were slow, and Colt was a poor manager, so in 1842 the Paterson factory shut down. Captain Samuel Walker, of the U.S. Regiment of Mounted Riflemen, had learned about Colt firearms during the Seminole wars and from his service as a Texas Ranger (the state police force of the Republic of Texas). In 1846, during the Mexican War, General Zachary Taylor ordered Walker to procure Colt guns for the U.S. Army in Mexico. Colt incorporated suggestions from Captain Walker to improve the front and rear sights, install a lever for easier loading, and reconfigure the grip. The Army ordered one thousand six-shooter handguns, in .44 caliber, and Colt was back in business.


Samuel Colt. (Library of Congress)

The 1849 California gold rush increased civilian demand for the guns and established the Colt name as synonymous with the American West. Colt traveled tirelessly to promote his products. In 1850, he was commissioned as a lieutenant colonel in the Connecticut State Militia, a title that made it easier for him to obtain sales meetings with foreign dignitaries.

Revolvers began to achieve mass popularity in England after Colt displayed his guns at London's 1851 Great Exhibition of the Works of Industry in All Nations, held at the Crystal Palace. The British army and navy bought large quantities, including over twenty thousand revolvers in 1854-1855 for use in the Crimean War. Colt's Pimlico factory in London was the first foreign factory opened by an American, although the factory closed a few years later because of British competition.

By the time the British were suppressing the Indian Mutiny of 1857-1858, the favored British revolver was the one invented by the Briton Robert Adams. (Colt's relevant patents expired in Britain in 1849, but not until 1857 in the United States, so competition came to the United Kingdom sooner.) The Adams revolver was double-action: pulling the trigger would not only fire the cartridge but also recock the hammer, and thereby rotate the cylinder. Although the Adams revolver was less accurate than the Colt, especially at longer distances, the British preferred its faster rate of fire.

To make guns for the Mexican War, Colt had subcontracted the job to a factory in Whitneyville, Connecticut, owned by Eli Whitney, Jr., son of the inventor of the cotton gin. The younger Whitney taught Colt a great deal about industrial mass production. Colt applied Whitney's ideas and advanced them (thanks in part to his brilliant employee Elisha K. Root), first at a factory that Colt rented in Hartford, and then in the massive Hartford factory he built in 1855.

Before Colt, firearms were built one at a time by gunsmiths who made individual parts as they went along. Colt brought standardized production to firearms manufacture. At the Hartford factories, all parts were made by semiskilled laborers using machine tools, Because each part was made within defined tolerances, the various parts could be readily assembled into a completed firearm. Each gun was the product of several hundred standardized machine operations—as well as dozens of precise inspections. The uniform sizing of interchangeable parts meant that customers could order spare parts, or replacements for broken parts, which would be certain to fit their own gun.

After the London exhibition, the British came to Colt's factory to study what was called "the American system": production lines producing high volumes of high-quality products based on precisely engineered interchangeable parts. Although European tradition insisted that lovely objects could only be created by expert craftsmen working slowly, Colt's mass-produced guns had beautiful form, finish, and colors—some guns with a style that anticipated Art Deco.

While textile mills in New England treated workers as interchangeable inputs who could be discarded or used up, Colt treated his employees well. To maintain the highest quality in work, he limited shifts to ten hours per day, plus a full one-hour lunch break. Sanitation standards at the factory were high, with wash basins, towels, soap, and hot and cold water. Near the factory, Charter Oak Hall was perhaps the first employer-built social center in America, with games and reading material. Charles Dickens, a harsh critic of social injustice in England, praised Colt's factory in an 1854 issue of Dickens's magazine *Household Words*. Colt also imposed high standards on his outside contractors, severing relationships with contractors who imposed long hours or who did not pay well. He saw high employee morale as essential to mass production of high-quality products.

An innovative marketer, Colt was apparently the first to use the phrase "new and improved" in advertising. Celebrity endorsements, particularly from military figures such as future U.S. presidents Zachary Taylor and Franklin Pierce, were also a major element in his promotions. Colt worked very hard all his life and eventually worked himself to death, falling prey at age forty-seven to a cold, his condition having been weakened by several years of what might have been rheumatic fever, gout, or malaria. Although Colt died in 1862, his company, with several changes of official names and owners, continues in business to this day and has produced many other innovations in handguns and rifles, and in industrial manufacturing. Among the most notable post-1862 Colts are the 1873 Peacemaker revolver and the Model 1911 self-loading

THE COLT REVOLVER

The oldest surviving revolver dates to 1597. Before Samuel Colt's revolver, the most common multishot handgun was the large and awkward pepperbox; it could fire four to six rounds, with each round having its own barrel and firing chamber. Single-barrel revolvers had already been conceptualized and manufactured based on the principles of Captain Artemus Wheeler, who patented a flintlock revolver carbine in 1818. Such revolvers were improved and commercialized by Elisha Collier, but the Collier guns did not work well. He shut down his firearms business in 1828.

Colt made a reliable revolver that could use percussion cap ammunition (the most advanced ammunition of the time) and whose cylinder did not need to be rotated by hand. It was the first mass-produced revolver. The original Colt revolvers were all single-action—that is, the shooter would use his thumb to pull back, or cock, the hammer into a fixed position. The act of cocking the hammer would engage the pawl (a lever connected to ratchets on the cylinder). The ratchet motion would index the cylinder, bringing the next cylinder chamber into alignment with the barrel. When the hammer was cocked, a lever locked the cylinder into alignment with the barrel. Pulling the trigger would drop the hammer, which would hit the percussion cap, igniting the gunpowder, which would propel the lead bullet down the barrel and toward the target. To fire the next shot, the shooter would start the process again by thumb-cocking the hammer.

The cylinder was mounted on a central rod (arbor), to which the barrel was also mounted, and was locked onto the frame by a pin that fit into holes in the barrel and arbor. The cylinder was partitioned so that the percussion cap for one round was isolated from all the other percussion caps. This usually prevented the flash of a single percussion cap from igniting any other percussion cap. Later models by Colt chamfered the cylinder chamber mouths. The chamfering deflected outward the escaping gases from the gunpowder explosion, further reducing the risk that the gas would ignite the percussion cap in an adjacent chamber.

pistol. The latter gun, with slight modifications, is widely produced today and is still regarded by many experts as the best self-defense gun.

IMPACT

Before the invention of the Colt revolver, warring Indians could fire several arrows in the time it took a white soldier to fire and reload a single shot from a gun. At "Hays' Big Fight" in July, 1844, fifteen mounted Texas Rangers (led by Captain John Coffee Hays and including Samuel Walker) faced eighty mounted Comanches at a tributary of the Pedernales River. At the time, the Comanches were the greatest light cavalry in the world. Nevertheless, the Texans had Colt's revolvers, and the battle ended with half the Comanches killed or wounded. The Colt handgun not only provided firepower superiority over the Indians but also could readily be fired one-handed by a horseman. It changed the balance of power and was the foundation of white victories over the Indians in Texas and many other places in the West.

During the American Civil War, Colts were the most common revolver on both sides. As in most wars, handguns were carried mainly by officers. Colt's factory manufactured about 200,000 revolvers during the war, selling 127,000 to the U.S. Army and the rest to individual purchasers in the Union. In the 1861-1866 period, Colt's firearms accounted for 39 percent of U.S. government firearms acquisitions (mostly the Army Model handgun).

Even more significant, Colt's six-shooter was small enough to be carried routinely by a civilian and had enough firepower for a small person to defend him or herself against a group of larger assailants. For the first time ever, no longer were a group of large males the almost-sure winner of a violent confrontation with a woman or a smaller man. After the Civil War, a popular saying was "Abe Lincoln may have freed all men, but Sam Colt made them equal." The Colt revolver was one of the greatest advances of self-defense in all of human history.

—David B. Kopel

FURTHER READING

Boorman, Dean K. *The History of Colt Firearms*. New York: Lyons Press, 2001. Coffee-table book with many beautiful photographs, covering all Colt firearms from the 1830's to the present.

Edwards, William B. *The Story of Colt's Revolver*. Harrisburg, Pa.: Stackpole Press, 1953. An impressively thorough biography, replete with extensive correspondence to and from Colt, copies of patents, government documents on the testing and purchase of Colt guns, and product advertisements.

Houze, Herbert G., et al. *Samuel Colt: Arms, Art, and Invention*. New Haven, Conn.: Yale University Press, 2006. A beautiful book with hundreds of photographs of firearms, the manufacturing process, paintings, the Colt family tree, and other Colt memorabilia, assembled for a special Colt exhibit at the Wadsworth Atheneum in Hartford. The book also contains extensive text, well-researched and footnoted, about Samuel Colt and the business he built.

Wilson, R. L. *Colt: An American Legend*. New York: Abbeville Press, 1985. The official history of Colt firearms. Serial number tables for all models. Lavishly illustrated with over four hundred pictures and aimed mainly at collectors.

See also: John Moses Browning; Richard Gatling; Samuel F. B. Morse; John T. Thompson; Eli Whitney.

William Fothergill Cooke

English electrical engineer

Cooke was one of the chief pioneers of telegraphy in Great Britain, working in collaboration with Charles Wheatstone. Although most commentators consider that Cooke's contribution to the partnership was more on the business side than on the scientific side, Cooke certainly did not see it that way himself.

Born: May 4, 1806; Ealing, Middlesex, England
Died: June 25, 1879; Farnham, Surrey, England
Also known as: Sir William Fothergill Cooke
Primary fields: Communications; electronics and electrical engineering
Primary invention: Electric telegraph

Early Life

William Fothergill Cooke was one of the four children of William Cooke, a surgeon, and his wife, Elizabeth Ann (née Fothergill). The elder William Cooke was elected as physician to Durham Infirmary in 1822—a post that he held until 1842. The younger William was therefore sent to Durham School, having presumably received his earlier education in Ealing for two years before going up to Edinburgh University. He did not graduate but went into the Indian army, becoming an ensign; he resigned his commission after five years after returning to England suffering from ill health.

Following his return from India, Cooke decided to follow in his father's footsteps, and he studied anatomy in Paris, where he developed a remarkable facility for making dissection models in colored wax. That skill won him an invitation to visit the Anatomical Institute in Heidelberg, Germany, and while he was in that city he attended a demonstration given on March 6, 1836, by the professor of natural philosophy at Heidelberg University, Geheime Hofrath Moncke, of a telegraph apparatus based on a design by the Russian baron Pavel Schilling.

Cooke immediately realized the potential of the technology, especially in connection with the railway systems then in their early development, and he also realized that a race had begun to develop a commercially viable system. He promptly abandoned his medical studies in order to devote himself to telegraphy, returning to England in April, 1836, and began experiments in collaboration with a solicitor named Burton Lane. He commissioned an apparatus for exhibition from a clockmaker in Clerkenwell, who might well have been the same one who employed Alexander Bain, the inventor of the chemical telegraph, when the latter arrived in London the following year.

Cooke could not get his initial apparatus to work over long distances. He appears to have been ignorant of the implications of Ohm's law relating to electrical resistance, and he could not understand why his signals lost strength as they traversed the connecting wire. He sought help from Michael Faraday and Peter Roget of the Royal Society, but they could not offer him a practical solution to the problem. Roget referred him to Charles Wheatstone, who was then trying to develop a telegraph apparatus of his own; the two met for the first time on February 27, 1837, and formed a formal partnership of collaboration in May of that year.

Life's Work

Cooke had already been in negotiation with the Liverpool and Manchester Railway Company for the use of telegraphy in signaling before he formed his partnership with Wheatstone, but it was not until Wheatstone solved the problem of long-distance transmission that the partners were able to produce their first workable system. The device was patented on June 12, 1837. Using a twelve-mile wire, Robert Stephenson helped Cooke set up a test between London's Euston Station and Camden Town Station. Various other railway companies tested the device, but it was deemed to be too expensive to be useful.

The principal problem with the initial Cooke-Wheatstone model was that it used five signaling needles and line wires in order to set up sufficient combinations of signals to encode the twenty-six letters of the alphabet. Cooke and Wheatstone developed a two-needle model in 1838, but it was still too costly. The American inventor Samuel F. B. Morse was a year behind them in filing his own key patent for a telegraph system, but he was quicker to adopt a binary code developed in Germany by Carl August von Steinheil and thus obtained a narrow lead in making telegraphy economically viable. It was not until Cooke and Wheatstone produced and patented a single-needle apparatus in 1845 that the application finally became economically viable; it was then swiftly adopted by all the railway companies in Great Britain.

On June 5, 1838, Cooke married Anna Louisa, the daughter of Joseph Weatherly, a solicitor from Rotherham; they had one daughter. By that time, Cooke and Wheatstone were already somewhat at odds, and they eventually fell out in spectacular fashion in 1841 over the question of entitlement to the credit for their achievements. Their quarrel dragged on long after the dissolution of their formal partnership. The dispute was taken for arbitration, Sir Marc Isambard Brunel representing Cooke and Professor John Frederic Darnell representing Wheatstone; their carefully mediated decision that Cooke and Wheatstone were equally responsible for the invention of the telegraph satisfied neither of the contending parties.

Wheatstone and Cooke clashed again when Cooke and John Lewis Ricardo—the nephew of the famous economist David Ricardo and the chairman of the North Staffordshire Railway—set up the Electric Telegraph Company in 1846, initially with Wheatstone's cooperation. The formation of the company was complicated by claims from several other inventors who had patented relevant devices, most notably Alexander Bain. A parliamentary commission had to be appointed to sort out the various claims; although Bain was compensated to the tune of £7,500 and Wheatstone to the tune of £33,000, Cooke was the big winner, his patents eventually being bought by the company for £120,000. The company went on to become a great success; it eventually merged with the International Telegraph Company in 1856.

The dispute between Cooke and Wheatstone went into a further phase when Cooke published a combative pamphlet in 1854 entitled *The Electric Telegraph: Was It Invented by Professor Wheatstone?*—a question to which he replied, resoundingly but probably inaccurately, in the negative. Wheatstone replied in kind the following year, but he did not have Cooke's mastery of the polemic style, and he only prompted further assertive publications from Cooke in 1856, 1857, and 1866.

Cooke attempted to obtain extensions of his early patents, but the Privy Council decided that he had been sufficiently remunerated and refused the extension. Without the ingenious Wheatstone to assist him, he made no headway with further inventions of his own, but he had already made his mark. He and Wheatstone jointly received the Albert Gold Medal of the Society of Arts in 1867, and Cooke was knighted in 1869, a year after Wheatstone. Cooke began investing in mining enterprises in North Wales in the hope of increasing his fortune, but he lost it instead and was reduced to relative poverty. He was granted a civil list pension in 1871, but he ended up living with his son-in-law, in whose home he died in 1879. His wife survived him, living until 1891.

IMPACT

It is impossible to separate Cooke's impact on the history of technology from that of his collaborator Charles Wheatstone. Wheatstone undoubtedly had some justice in his claim to be due the larger share of the credit for the inventive component of their joint enterprise, but he was

THE ELECTRIC TELEGRAPH

The principle of telegraphy is relatively simple. A transmitting device in which a needle is moved by an electromagnetic field, making intermittent contacts, produces signals that are transmitted through a copper wire to a distant receiver, which reproduces the signals in some decodable form, usually as sounds. The possibility had been pointed out by Pierre-Simon Laplace and further popularized by André-Marie Ampère before numerous inventors began to produce actual models; Pavel Schilling's was not the first, but it was by far the most widely publicized. William Fothergill Cooke and Charles Wheatstone were not the only Englishmen working on the problem in 1837-1838, but the Devonshire surgeon Edward Davy did not follow through with his model, leaving them a clear field in Great Britain, although their slowness in developing a single-needle system using a binary code disadvantaged them relative to Samuel F. B. Morse in the United States. Cooke and Wheatstone first developed a five-needle telegraph system to indicate the alphabet, but the device was not economically viable compared to Morse's simpler single-needle system, which used a system of dots (short signals) and dashes (long signals) to represent letters. Cooke and Wheatstone finally produced and patented a single-needle apparatus in 1845.

The patterns of the technology's development differed markedly between the United States and Europe because geography imposed different priorities. Railway systems were developed more rapidly in the compact countries of Western Europe, and it was entirely natural for Cooke and Wheatstone to give initial priority to railway signaling, while the vast open spaces of America meant that the primary emphasis had to be more narrowly devoted to the long-distance transmission of information. Within a relatively short space of time, however, transatlantic cables were laid and telegraphy became a key mode of communication between as well as within continents. The technology swiftly revolutionized communications in news, business, and warfare, and everyone who had a significant hand in its development had good claims to have played an important role in the development of modern civilization.

always ready to appropriate the work of others into his own devices and might have overestimated the value of his personal contribution. Cooke certainly overestimated, or at least overrepresented, his technical contribution. Nevertheless, the fact remains that it was Cooke who saw and felt the urgency of pushing through the original idea, and it was certainly Cooke's business acumen rather than Wheatstone's technical ingenuity that succeeded in establishing their apparatus as the standard model in Britain. If Cooke was overcompensated by the Electric Telegraph Company by comparison with the other claimants, at least he had the good grace to throw the money away on reckless investments. The telegraph itself went on to have a tremendous impact on nineteenth century communications, not merely in connection with railway signaling but also in the general transmission of information.

—*Brian Stableford*

FURTHER READING

Bowers, Brian. "Inventors of the Telegraph." *Proceedings of the Institute of Electrical Engineers* 90, no. 3 (March, 2002): 436-439. A brief but scrupulous attempt to weigh up the relative contributions of Cooke, Wheatstone, and Morse to the early development of telegraphic technology.

Burnley, James. "Sir William Fothergill Cooke." Revised by Brian Bowers. In the *Oxford Dictionary of National Biography*, edited by H. C. G. Matthew and Brian Harrison. New York: Oxford University Press, 2004. A brief and rather scanty biographical sketch, to which relatively little was added for the benefit of the new edition; it draws a good deal of information from a memoir by Latimer Clark and seems to regard the data given in Cooke's own self-serving pamphlets with some suspicion—as does Munro.

Hubbard. Geoffrey. *Cooke and Wheatstone and the Invention of the Electric Telegraph*. London: Routledge, 2008. A new edition of a book initially published in 1965 that offers a definitive account of the problematic relationship between Cooke and his collaborator, and their joint contribution to the development of telegraphy in Britain. Endeavors to strike a judicious balance in assessing the two men's rival claims and is more successful in that regard than most earlier accounts.

Morus, I. R. "'The Nervous System of Britain': Space, Time and the Electric Telegraph in the Victorian Age." *British Journal of the History of Science* 33, no. 4 (2000): 455-476. A comprehensive account of the development of telegraphy in Britain. Better informed and better balanced than Munro but not as broad in its scope.

Munro, John. *Heroes of the Telegraph*. Whitefish, Mont.: Kessinger, 2004. A new edition of a popular work first published in 1883 that relegates Cooke's biography to an appendix while granting Wheatstone a chapter because, in Munro's opinion, Wheatstone was a "man of science" and Cooke a mere businessman—a prejudice that many other historians of science have shared but that might not be entirely just.

See also: Alexander Bain; Michael Faraday; Samuel F. B. Morse; Charles Wheatstone.

WILLIAM DAVID COOLIDGE

American engineer and physicist

Coolidge is best remembered for developing the ductile tungsten filament for lamps in 1911 and for creating the Coolidge tube, which improved the operation of Wilhelm Conrad Röntgen's X-ray machine. He was also instrumental in developing polymeric materials and silicones that became essential components of electronics after World War II.

Born: October 23, 1873; Hudson, Massachusetts
Died: February 3, 1975; Schenectady, New York
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Ductile tungsten; Coolidge tube

EARLY LIFE

William David Coolidge was born in Hudson, Massachusetts, a town about twenty-five miles from Boston, on October 23, 1873. The son of Albert Edward Coolidge, a small farmer and shoemaker, and Mary Alice Shattuck Coolidge, a dressmaker, William was descended from an illustrious family that had arrived in Boston in 1630 and numbered among its members Calvin Coolidge, the thirtieth president of the United States. William, nicknamed Will, received his primary education in a humble one-room school where a single teacher worked hard to educate students of all grade levels together. The limits of his education, however, did not keep him from excelling; he showed exceptional abilities not only in his studies but also in sports and other outdoor activities, such as hiking and fishing. Fascinated by photography, Coolidge built his own camera while he was still in elementary school and outfitted a darkroom in his parents' house; this childhood passion remained his most enjoyed hobby over the entire course of his life.

After finishing elementary school, Coolidge went on to Hudson High School, where he excelled in mathematics and physics, graduating as valedictorian of his class of thirteen students. Because of his family's limited financial resources, after graduation he took a job in a factory that manufactured rubber garments instead of going to college. Fortunately, a friend suggested that he apply for a scholarship at the local college known as Boston Tech, which was, in fact, the Massachusetts Institute of Technology (MIT). His excellent high school grades combined with his mechanical and electrical skills won him the award, and in September, 1891, at age seventeen, Coolidge entered MIT. Studying electrical engineering, chemistry, physics, and modern languages, he was immediately impressed by his chemistry professor, Willis R. Whitney, who in turn was delighted to have such a dedicated student.

During the summer of his junior year at MIT, Coolidge earned an internship at Westinghouse Electric in Pittsburgh, Pennsylvania. His experience at Westinghouse taught him that he was not well adapted to conducting engineering research in a company setting; he was much better suited to laboratory experimentation. When he graduated in 1896, with the encouragement of Professor Whitney, Coolidge applied for a scholarship to go to Leipzig, Germany, to study physics under the guidance of Gustav Wiedemann and Paul Drude. Accepted into the program, he financed his adventure through a combination of a scholarship and money borrowed from a friend. The investment turned out to be a good one; in just three years, Coolidge completed his studies and received his doctorate in physics.

LIFE'S WORK

With his impressive record at Leipzig, where he had earned his Ph.D. with the highest possible grade, Coolidge was offered a teaching position in the Physics Department at MIT. For the next five years, he taught, assisted professor of chemistry Arthur Amos Noyes, and continued to work with his mentor, Whitney.

Whitney was in charge of the new General Electric (GE) Research Laboratory in Schenectady, New York, and so was able to offer a position there to Coolidge, whose potential for research he had cultivated and highly respected. After a successful negotiation in which Coolidge secured a salary that was twice what he had been earning at MIT and gained the right to use half his time (and the laboratory's equipment) for his personal research, Coolidge accepted the position. Beginning in 1905, one of his first projects focused on improving Thomas Alva Edison's lamp; his work resulted in the creation of a light bulb that was three times more powerful than Edison's. The profits that General Electric real-

THE COOLIDGE TUBE

The Coolidge tube is a glass tube in which X rays are produced. William David Coolidge, impressed by Wilhelm Conrad Röntgen's discovery of X rays, set out to build a machine that could produce the high voltages indispensable to obtaining them. Basing his mechanism on Röntgen's work, Coolidge produced a device in which air was contained at low pressure in a tube where its positive ions struck the cathode, generating electrons that in turn struck the anode, generating X rays. His machine was sufficiently successful to be purchased by a local physician for X-ray diagnosis.

A decade later, while working on ductile tungsten and molybdenum in 1909, Coolidge experimented with these two chemicals to see if they could be used as X-ray targets. Three years later, after tungsten had been used successfully to mass-produce Mazda C bulbs, Coolidge tried to use solid tungsten as the cathode and anode of an X-ray-generating tube that replaced low-pressure gas with a vacuum. Working with his colleague Irving Langmuir, Coolidge had realized that the hot metal of the cathode in a vacuum emits electrons (this effect had been studied previously by Thomas Alva Edison, who called it the "Edison effect"; today scientists use the term "thermionic emission"). By heating the cathode in his tube, Coolidge could generate X rays more reliably than was the case with the previous system using low-pressure gas.

Different Coolidge tubes were produced according to their intended uses. The first tube that was produced immediately proved itself to be useful for dental diagnosis and found a ready market. Further development of larger units extended the popularity and application of Coolidge tubes in radiology. During World War I, Coolidge was asked to create portable units to be used in field hospitals. Later, when physicians hoped to extend the use of X rays for deep therapy, Coolidge successfully developed a process to increase the voltage of his tubes while keeping the target cool by irrigating it with a flow of cold water.

ized from this extremely popular innovation more than justified both Coolidge's salary and the company's massive investment ($116,000) in the construction of the laboratory.

Financially secure in his new position, on December 30, 1908, Coolidge married Ethel Woodward, the daughter of the president of a local bank. Their marriage produced two children, Elisabeth and Lawrence, but ended in tragedy when Ethel died in 1915 of an infectious disease. Soon after, Coolidge hired Dorothy Elisabeth MacHaffie, a nurse, to care for his two young children. Within a year, Coolidge married her.

At the laboratory, Coolidge continued to search for ways to improve the light bulb, experimenting with different substances to be used as filaments, until a lamp using tungsten was produced in Austria. Although the tungsten filament produced a very bright light, researchers in Europe and at General Electric were confronted with a major problem: The brittleness of the filament rendered the bulb extremely fragile. After three years of intense research, Coolidge discovered a method to make tungsten ductile (capable of being drawn out into a very thin wire or thread) at room temperature through the addition of 1 percent of thorium. The result was a flexible, durable filament that was so thin that a single pound of tungsten made a wire 8.5 miles long and would be sufficient to produce twenty-three thousand bulbs. This new incandescent lamp was produced in 1911.

Two years earlier Whitney had hired Irving Langmuir, who had worked on heat transfer in gases at high temperatures. Langmuir suggested that Coolidge could double the light output of his bulbs by replacing the vacuum previously used with an inert gas. The collaboration between Langmuir and Coolidge resulted in the production of General Electric's best-selling Mazda C light bulb.

In the months following the development of ductile tungsten, Coolidge explored its application to a variety of problems, employing it to replace platinum in telegraph keys, auto ignitions, and other equipment controls. His most significant discovery, however, came when he used the tungsten to make a source of X rays that was dramatically more dependable than previously available sources. Wilhelm Conrad Röntgen, a German physicist, had discovered X rays in 1895, and Coolidge had met Röntgen briefly when he was studying in Leipzig. There was a certain parallel between the development of the bulb Coolidge had worked on and the bulb that Röntgen used to produce X rays. Coolidge's idea, for which he received a patent in 1913, was to replace the low-pressure gas in Röntgen's X-ray-generating tube with a vacuum in which a thick tungsten filament, when heated by an electric current, would generate a continuous and ample stream of electrons. This invention, which became known as the Coolidge tube, was hailed as a breakthrough that could produce electrons "in the same quantity every second as a ton of radium." The value of the Coolidge tube in improving X-ray diagnosis was immediately recognized by both physicians and the scientific community. Coolidge received the Rumford Prize of the American Academy of Arts and Sciences in 1914 for his experimental achievements on "ductile tungsten and its application in the production of radiation."

With the onset of World War I, Coolidge and the GE Research Laboratory plunged into the vital scientific support of the war effort. Coolidge's development of portable X-ray machinery immeasurably improved battlefield diagnoses of injuries and saved countless Allied lives, but his greatest contribution came when GE, the Submarine Signalling Company, and Western Electric collaborated to produce an effective submarine detection system based on sealed rubber binaural listening tubes—"C tubes"—that Coolidge produced. Supplied with these devices in 1918, Allied navies were able to end the dominance of German U-boats in the Mediterranean, an important factor in the ultimate Allied victory.

On November 1, 1932, after the economic pressures of the Great Depression had overwhelmed the retiring Willis Whitney, Coolidge became director of research at the GE Research Laboratory, where he took on the challenge of ensuring the laboratory's survival in hard times. Through remarkably careful management, Coolidge succeeded, and by 1940, as the economy improved, he began to envision his own retirement. Unfortunately, world events interfered, and Coolidge decided to stay at his post for the duration of World War II. A member of President Roosevelt's Advisory Committee on Uranium, Coolidge was involved in the development of the atomic bomb, bringing valuable practical engineering skills to the project. Coordinated with other institutions through the government's Office of Scientific Research and Development, Coolidge and the GE Laboratory also contributed to the development of microwave radar as well as radar and radio countermeasures.

With the end of the war finally in sight, Coolidge finally retired on January 1, 1945. Retirement, however, did not end his intellectual activity. Blessed with remarkably good physical and mental health, Coolidge continued to visit the GE Laboratory, advising the next generation of researchers there until shortly before his death, at 101 years of age, in 1975.

IMPACT

Coolidge is remembered for his development of ductile tungsten and for the invention of the Coolidge tube, which revolutionized radiology; he is also remembered for his development of essential technological applications that helped to win both world wars. During his lifetime, Coolidge was awarded eighty-three patents and received numerous prestigious honors, such as the Washington Award of the Western Society of Engineers (1932), the John Scott Award granted by the City Trusts of the City of Philadelphia (1937), the Faraday Medal of the Institution of Electrical Engineers of England (1939), the Duddell Medal of the Physical Society of England (1942), the Franklin Medal of the Franklin Institute (1944), the first K. C. Li Gold Medal for the Advancement of the Science of Tungsten by Columbia University (1951), the Röntgen Medal (1963), and the Climax Molybdenum Wedgwood Medallion (1973). In 1972, Coolidge was the first recipient of an annual award named in his honor, the William D. Coolidge Award, presented by the American Association of Physicists in Medicine.

Even though Coolidge made such essential discoveries, he always stressed that they had been the fruits of intense labor by a team of researchers at the laboratory and could not possibly be attributed to his work alone. He was regarded by his colleagues as an honest, quiet, modest, and energetic man.

—Denyse Lemaire and David Kasserman

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See also: Thomas Alva Edison; Irving Langmuir; Wilhelm Conrad Röntgen.

MARTIN COOPER

American electrical engineer

In spearheading two decades of research into developing the first mobile (entirely wireless) telephone, Cooper, an electrical engineer working at the time for Motorola, revolutionized telecommunications for both personal and corporate use by investing phone users with unprecedented freedom and mobility.

Born: December 26, 1928; Chicago, Illinois
Primary fields: Communications; electronics and electrical engineering
Primary invention: Mobile phone

EARLY LIFE

Martin Cooper was born the day after Christmas in 1928. An inquisitive child, fascinated by the family's cathedral radio and by the telephone on the parlor wall (he dismantled both devices and reassembled them with ease), Cooper determined early on that he would study electronics. He attended the nearby Illinois Institute of Technology (IIT), founded only a decade earlier and considered a cutting-edge facility for students eager to help convert the considerable body of war technology into useful (and revolutionary) peacetime applications.

After graduating with honors in 1950 with a degree in electrical engineering, Cooper enlisted in the Navy that year, certain that defense technologies represented the most comprehensive application of new theories in electronics, communications, and computer technology. During a four-year stint, Cooper served on a submarine and two destroyers, learning with remarkable proclivity the ships' massive electronic communications systems. Returning to Chicago, Cooper was hired by Motorola in 1954 and placed in the systems division, in charge of developing portable communications products. Gifted with an intellectual curiosity (he was later inducted into Mensa, the high-IQ society), while he worked at Motorola he also completed his master's degree in electrical engineering at IIT (1957). During his tenure, research into mobile communication was centered on providing vehicular phones for police, firefighters, and paramedics. Although gratified by providing new technologies for such service occupations, Cooper was restless, certain that mobile communications could ultimately be provided to the consumer, that communications could be freed from land wires that bound communication to a particular home or business. In the late 1960's, he was placed in charge of Motorola's division of cellular research aimed at developing a prototype of just such a device.

LIFE'S WORK

Historically, the foundation premise for wireless communication actually dates to before World War I, when American Telephone and Telegraph (AT&T), for most of the century the communications monopoly in the United States, vetoed in-house proposals to develop the technology, fearing it would compromise its monopoly on landwire service. It would be more than three decades (1947) before Bell Laboratories, a massive conglomerate with government-funded research facilities, drew up preliminary drafts of a wireless cellular network in which portable phones in cars would use a matrix of cells, or small overlapping service areas, to pass a signal along using elevated base stations with microwave antennas, a structured network of cells to help citywide emergency services. Initial success in the mid-1950's encouraged

Martin Cooper holds a Motorola DynaTAC 8000X (1973), the first handheld cellular telephone. (AP/Wide World Photos) development of a theory that using smaller cells—that is, decreasing the range of service—would significantly increase the volume of signals the system could manipulate (the signal could be tracked and switched from one base to another) and thus make possible, at least theoretically, handheld cellular phones.

It was upon this body of research that Cooper directed his Motorola team. At the time, Motorola was considered a minor presence in the communications industry without the resources of Bell, but this did not deter Cooper, whose vision of a personal phone provided the visionary energy for the project (with typical self-deprecating humility, he would later claim the idea came to him from watching *Star Trek* and the *Enterprise* crew's communicators). On April 3, 1973, Cooper flew to New York City with a prototype portable phone, intending to demonstrate it for the Federal Communications Commission (FCC) at the Manhattan Hilton. In what has become a legend in the communications history of the twentieth century, Cooper paused a moment on his way to the meeting and, there on the sidewalk, amid pedestrian traffic and against the noise of a Manhattan afternoon, calmly pulled out the Motorola DynaTAC 8000X (Dynamic Adaptive Total Area Coverage), the bulky (close to two and one-half pounds and about the size of a brick) prototype. Without fanfare, he made the first cellular phone call. The phone set transmitted the signal off a base station positioned atop the nearby Burlington Consolidated Tower. Cooper heard the familiar ringing. As he would relish telling for years, he had called the competition at rival Bell Labs.

CELLULAR PHONES

It is difficult today to appreciate the groundbreaking work of Martin Cooper's team—his prototype appears clunky and looks more like a shoe phone—largely because of the breakneck speed of technological evolution that so quickly reshaped his cellular phone. (Cooper famously observed that within a decade of the phone's first use, he had become not the father but the grandfather of the cell phone.) When it is recalled that in 1973, when Cooper made his first call, phones still had cords and the global communications network relied entirely on land wires, the audacity of Cooper's research team can be appreciated. The initial design called for entirely redesigning the shape of the phone itself as well as conceptualizing a computer system and the physical infrastructure to support the phone. Creating the prototype cellular phone was enormously challenging for Cooper's research team, as no model of such a device actually existed. All the technology and all the innovations were done specifically for the test model (although much of the initial work relied on patents Motorola already held in two-way radio transmitters and semiconductors).

The DynaTAC 8000X (Dynamic Adaptive Total Area Coverage) prototype was based on the premise that a caller's signal would be switched from one coverage area (cell) to another as the user moved. The earliest models of the cellular phone were little more than elaborate battery-operated walkie-talkies, or, more precisely, radios that sent and received radio frequencies and depended on base stations to relay the signal. As Cooper envisioned expanded use, however, low-powered transmitters in each cell would allow frequencies to be reused simultaneously in other nearby cells—thus eliminating the problem faced by earlier car phones of long waits for signals to be relayed. Computerized network equipment tracked the signal, and antennae transmitted the signal like a radio station. The same computerized tracking system maintained the signal's integrity amid other cell calls, those signals handed off through the network of directional antennae. As Cooper and his team had envisioned, as cell phone use inevitably increased, the system could accommodate virtually unlimited signal transmission by making the cell regions themselves progressively smaller, thus enabling more signals but still maintaining necessary clarity.

There were of course significant challenges before that prototype could be introduced to a mass market. By some estimates, Motorola alone spent more than $100 million in research. Within five years, a prototype system able to service a little over two thousand customers was piloted in Chicago. Over the next ten years, communications technology (largely credited to Bell Labs) addressed the construction of thousands of cell stations to transmit signals. In 1983, the FCC granted Motorola permission to market the DynaTAC 8000X, which was 10 inches long, was rectangular, and weighed 28 ounces. Initial talk time (roughly thirty-five minutes before recharging) was significantly increased, and the cost came down as parts were standardized and durability significantly increased, although the cost of the 1983 unit was still $3,500.

The impact of the so-called radio telephone system was immediate, and Cooper was singled out as the "father of the cell phone," although he was clear that his work rested on the efforts of the skilled team at Motorola. Consumer demand was historic—the phones were hailed not only as a status symbol but also as a necessary element for safety. Businesses quickly saw the potential for converting previously dead time to productivity. By the end of the 1980's, close to two million customers were using cellular service. Cooper, now a visionary in the field, left Motorola (at the time of his departure, in addition to the cell phone work, he had been credited with important breakthrough work in high-capacity paging terminals and radio pagers) to cofound Cellular Business Systems. When he sold the firm to Cincinnati Bell, Cellular Business Systems had secured a remarkable 70 percent of the cellular industry as its customers.

In 1992, although in his mid-sixties, Cooper started his own communications company, ArrayComm, headquartered in San Jose, California. Certain that cell phone technology could be made far more accessible, efficient, and economical, Cooper spearheaded research into next-generation smart antenna software technology able to manage a higher traffic of calls more efficiently. Tireless in his promotion of wireless communication and a savvy entrepreneur with an intuitive appreciation for the dynamics of marketing, he became a sought-after motivational speaker in both management and communication theory. (He devised Cooper's law, which mathematically projected that since Guglielmo Marconi's initial transmission in 1895, the number of radio frequency conversations that can be concurrently conducted in a specific area had doubled every thirty months.) In addition, Cooper served on trade missions on behalf of the United States to introduce communication innovations in market-friendly countries, most notably China.

IMPACT

The cell phone reoriented not only the telecommunications industry but society as well. Like other groundbreaking inventions—among them the telephone, the car, and the airplane—the cell phone redefined the conception of how people define spatial society itself. By liberating the communications process from land wires, by putting communication freedom literally in the hands of the consumer, the cell phone created an entirely new conception of the global community. Phones were now about people, not places. Its most obvious impact has been felt in emergency conditions and the quick notification of appropriate help.

In addition to saving lives, cell phones have dramatically reconstituted the notion of accessibility: Conversations routinely are conducted with generous frequency, and despite a growing chorus of social commentators who see the increased chatter as trivializing the communication dynamic, the impact has been dramatic. The generation born after 1985 cannot imagine being bound to landline phones. As the cell phone has become less cumbersome and more versatile (permitting text messaging, Internet connections, e-mail delivery, digital photography, and game technologies), it is positioned to become the most important communication innovation since the telegraph. Of course, its prevalence has brought problems. In an effort to decrease the number of traffic accidents and fatalities linked to handheld cell phone use while driving, various states have introduced legislation restricting drivers from using the handheld devices. Establishments have created "quiet zones" to limit where cell phones can be used. Security issues have only begun to be addressed, given the massive amounts of data being freely transmitted. In addition, concerns have been raised over long-term exposure to cell phone radiation and its possible link to the development of brain tumors.

As Cooper tirelessly pointed out, the next generation of cell phone communications must work on more efficient relays and fewer dropped calls. The technology will become more transparent—that is, more complex yet manageable with fewer instructions. As Cooper sees it, the second wireless revolution will focus on low-cost data delivery, open access by using powerful cells in more places rather than relying on the current tower-to-tower transfer (the antennae create environmental dissonance and have raised the ire of nearby residents and generated concerns from pilots), and allowing the free market to bring the cost of the technology (and the calling programs) within the reach of virtually everyone. Conservative estimates, as of November, 2007, place the number of cell phone users worldwide at 3.3 billion.

—*Joseph Dewey*

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See also: Alexander Graham Bell; Ivan A. Getting; Elisha Gray; Alfred J. Gross; Guglielmo Marconi.

PETER COOPER

American industrialist

An industrialist, philanthropist, educator, and political reformer, Cooper patented farsighted inventions throughout his life. He improved processes for making glue, iron, and steel; first demonstrated the capabilities of the steam locomotive on American railways; and experimented with prototypes for a flying apparatus and endless-chain machines.

Born: February 12, 1791; New York, New York
Died: April 4, 1883; New York, New York
Primary fields: Food processing; household products; industrial technology; manufacturing; railway engineering
Primary inventions: Steam locomotive; glue-making process

EARLY LIFE

Peter Cooper was born in New York City in 1791. He was the fifth of nine children born to John and Margaret Campbell Cooper. Shortly after Peter's birth, John moved the family to Peekskill, New York, which is located on the Hudson River, about an hour north of Manhattan. John Cooper opened a general store and engaged in numerous homespun trades. Peter attended a Peekskill school for only a short period; his lack of a formal education would trouble him his entire life. At an early age, Peter, like many inventors, exhibited mechanical genius and a talent for making things with his hands. Assisting his parents in their chores, Peter became skilled at hatmaking, cobbling, and wagon making and built a crude washing machine out of barrels and wheels.

At age seventeen, Cooper moved to Manhattan, where he was an apprentice to the carriage-building firm of Burtis and Woodward for four years. During this period, Cooper invented a machine for mechanically mortising the hubs of carriage wheels and a machine for drawing power from the tides. After his apprenticeship, he bought a business manufacturing cloth-shearing machines. With Cooper making various improvements to the machines, the business was a success, and he felt sufficiently prosperous to marry Sarah Bedell on December 18, 1813. The first of their six children was born the following year. On March 27, 1815, Cooper patented a pendulum-swinging, musical cradle he had made for his son. He also entered the cabinet-making and grocery businesses.

LIFE'S WORK

In 1821, Cooper purchased a struggling glue factory located at Fourth Avenue and Thirty-third Street in Manhattan for $2,000. Refining and patenting various glues and glue-making processes, Cooper soon offered the finest glue products in the United States, rivaling the expensive imports from England and France. Soon, Cooper added an improved make of isinglass, neat's-foot oil, whiting, cement, and the first packaged table gelatin to his successful line of manufactured products. In 1849, Cooper relocated the factory to Maspeth in Queens County. The profits from the factory provided Cooper with his first fortune. Meanwhile, his daily activities and interests led him to other inventions. He invented a blade-revolving lawn mower, a torpedo for proposed use by the Greeks in their rebellion against the Turks, and even an experimental flying machine (which exploded, endangering Cooper and his youngest brother, Edward, who was assisting him). Peter also obtained patents for improvements in constructing steam boilers, grinding marble tabletops, and transporting salt.

During this period, Cooper was absorbed by the quest to build machinery that would lose as little energy as possible in operation. For example, he realized that a revolving crank lost energy at the two inert points in its wheel. He patented a system of rotating steam pistons to try to

A NEW PROCESS FOR MAKING GLUE

Peter Cooper's glue factory was his first great success and the lifelong basis of his fortune. It succeeded because Cooper invented a better process for making glue, allowing him to produce the highest quality glues at low prices. As U.S. patent law allows for innovative industrial methods to be patented, Cooper received a patent on April 29, 1830, for his new method. Glue was historically made by boiling animal matter until glue oozes out. The water holding this glue was called foot water. Cooper's patented method improved the process for evaporating the foot water to distill the glue. Cooper replaced the open boiler traditionally used for evaporating foot water with a double-basin method derived from kitchen techniques. He built a brick furnace with a flue leading to two basins, one placed above the other. The furnace applied heat to the water in the lower basin through the flue. The foot water was poured into the upper basin. The boiling water in the lower basin evaporated the foot water to the right consistency. This double-basin method made for a more standard evaporation and thus a finer-grained glue. With this process, Cooper could produce ten well-defined grades of glue. He developed a system of grading for glue quality that was adopted and widely used in the glue industry. Cooper's success with his glue factory illustrates well how innovative and ingenious ideas for industrial production, protected by patents, can lead to commercial and economic success.

solve this problem. He also formulated a concept of an endless chain as a way to power machines with their own momentum. He applied this concept to improve methods of filling a creek with sand in a chain of boxcars and to carry iron ore from mines to forges in a chain of buckets. More ambitiously, he proposed endless-chain techniques for hydraulically propelling boats, driving locomotives, and powering the elevated trains of New York City. Although not all of these ideas met with success, they do demonstrate the fertility of Cooper's mind in wrestling with perennial problems of technology and science. His concept of an endless chain can be seen as a precursor to the conveyor belt.

In 1828, Cooper purchased three thousand acres in Baltimore in anticipation of the launch of the Baltimore and Ohio Railroad, the first in the United States. Finding suitable timber and iron ore on the property, he built kilns for turning the wood into charcoal and a furnace for smelting iron. Dissatisfied with the slow progress of the railroad, in 1830 he constructed an experimental steam-operated locomotive that he called *Tom Thumb*. *Tom Thumb* was a four-wheel locomotive with a vertical steam boiler, improvised boiler tubes made from rifle barrels, and a blower pulley. Its success demonstrated the possibilities of steam locomotives and brought Cooper national fame; the sale of his Baltimore properties and iron mill brought him a second fortune. He then built an iron foundry on Thirty-third Street near Third Avenue in Manhattan. Cooper made innovative use of the hot-blast method and anthracite coal to "puddle," or stir, the liquid iron mixture. In addition to railroad tracks, the foundry manufactured various kinds of wire, including the suspension wire used for the Niagara Falls Bridge. Moving the foundry to New Jersey, Cooper became one of the largest iron producers in the country. In the 1850's, the foundry began producing structural iron beams used for the new architecture of skyscrapers. The foundry later pioneered the open hearth process for making steel. With his mix of successful industries, Cooper was the leading manufacturer in New York.

The year 1828 also marked Cooper's entry into the public life of New York City, where he served as an alderman from 1828 to 1831 and from 1840 to 1841. As a public official, he assessed and made recommendations as to technological issues facing the city's water supply and pedagogical issues facing the public school system. In 1855, his daughter Amelia married Abram Hewitt, who became an indispensable partner in Cooper's enterprises. The Cooper and Hewitt firm backed numerous major ventures, including Cyrus Field's transatlantic cable, which was completed in 1858.

Cooper's enthusiasm for technology and invention had an almost religious dimension. In the short autobiography he dictated from February 20 to April 17, 1882, Cooper spoke of science as the law of God by which humankind would be drawn into a peaceful and prosperous future.

Motivated by his belief in scientific progress as the wellspring of human life, and conscious of the difficulties posed for him by his lack of education, Cooper decided to use his fortune to build a free college of technology in New York City. He began building the school in 1853 on a city block he acquired bordered by Seventh Street, Astor Place, and Third and Fourth Avenues. The imposing edifice featured many of Cooper's farsighted architectural ideas, such as leaving a shaft for a yet-to-be-invented elevator. The Cooper Union for the Advancement of Science and Art opened on July 1, 1858. It had a night school of arts and sciences, a school of design for women, a library, and a program of public lectures and forums. All branches were free and were endowed by Cooper, his brothers and children, and philanthropist friends of Cooper and Hewitt such as Andrew Carnegie.

In his last decades, Cooper concentrated increasingly on philanthropy and politics. In 1863, he became president of the Citizen's Association, dedicated to reforming the machine politics of Boss Tweed's New York City. In 1876, Cooper was the Greenback Party's first candidate for president of the United States. Cooper had become a national advocate for paper money ("greenbacks") to replace gold and silver as the nation's chief currency, with the paper money to be issued, regulated, and backed by the federal government. The chief plank of his Greenback Party platform was the elimination of the gold standard, a proposal popular with workingmen. Although this proposal was much derided in its day, it would become America's monetary policy in the twentieth century. Cooper continued taking out patents to the end, including ones for powdering eggs and for propelling elevated railway cars. In 1883, Cooper died at the age of ninety-two, one of the most acclaimed citizens of New York City.

IMPACT

Cooper is the quintessential early American inventor and industrialist. Without a formal education, Cooper relied on his mechanical genius, his ingenuity, and his industry. Many of his ideas lacked a scientific basis, and some proved fruitless, although even then he often showed an intuitive grasp of some fundamental mechanical principle—endless-chain devices, a flying machine, elevators—that would be realized decades later. Where his ideas had a practical basis and were based on his powers of observation and of everyday mechanics, they rarely failed. In his manifold enterprises, he patented machines and processes, improved technology, and perfected industrial methods. His array of inventions was at the heart of his various businesses—glue making, iron smelting, steel production—and of the fortunes he accumulated. His industries were an important component in the success of American business. His patent for table gelatin would be acquired by manufacturer Pearle Wait and renamed "Jell-O," becoming one of the famous American food products of the twentieth century. When the first railroad track was laid down by the Baltimore and Ohio Railroad in 1827, there was uncertainty as to the best way to economically power the train. Cooper's *Tom Thumb* prototype engine demonstrated the capabilities of the steam engine locomotive for commercial transportation. Steam engines would become the chief engine for railroad traffic for the remainder of the nineteenth century.

If his lack of education hampered his scientific work, it also spurred his grandest philanthropic venture. Cooper established the Cooper Union for the Advancement of Science and Art as a free institution so that students with little means could receive a superior education. With great foresight, he provided for the education of women as well. Cooper Union immediately showed its importance for the nation on February 27, 1860, when the Republican candidate for president, Abraham Lincoln, delivered one of the most important speeches of his career in its Great Hall. In the century and a half since, Cooper Union has continued to play a vital role in New York City, while providing a superb education to tens of thousands of promising scholars.

—*Howard Bromberg*

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See also: Joshua Lionel Cowen; Peter Cooper Hewitt; Richard March Hoe; Elmer Ambrose Sperry; James Watt.

MARTHA J. COSTON

American engineer

Coston developed a pyrotechnic signaling device and code system for use at sea. For more than a century, Coston flares saved lives and property. They also gave the North a strategic edge during the American Civil War.

Born: April 10, 1828; New York, New York
Died: January 12, 1904; Washington, D.C.
Also known as: Martha Jay Coston (full name); Martha Hunt (birth name); Martha Jay Scott Coston
Primary fields: Communications; maritime technology; military technology and weaponry; navigation
Primary invention: Signal flares

EARLY LIFE

Martha Jay Coston was born in New York City in 1828 to John Scott and Rebecca (Parks) Hunt of Baltimore. Her father died when she was young, after which her mother moved the family from Baltimore to Philadelphia. As a girl, Martha enjoyed learning and preferred quiet times with her mother to the boisterous company of her elder siblings.

When she was fourteen, Martha met Benjamin Franklin Coston, an up-and-coming scientist five years her senior. He had a reputation as a prodigy; not yet twenty, he had invented a submarine vessel capable of staying submerged for eight-hour periods thanks to a chemical process that supplied breathing air. Benjamin and Martha became friends, and the young inventor took to visiting the schoolgirl at home and helping her with her studies.

The two obtained permission from Martha's mother to marry once Martha turned eighteen. In 1844, they decided to wed in secret, but the sixteen-year-old Martha could not hide the marriage from her mother for long. After reconciling with Martha's family, the newlyweds relocated to Washington, D.C. There Benjamin assumed an appointment as master in the service and head of the Washington Navy Yard laboratory.

The Costons flourished in the nation's capital, forming many social and political connections. However, in 1847, Benjamin resigned from the Navy, due in part to a disagreement with the government over his pay and position, as well as in part to a decline in health related to occupational chemical exposure. Benjamin, Martha, and their three young sons relocated to Boston, where Benjamin became president of a gasworks.

Not long after the birth of their fourth boy, Benjamin became severely ill. Martha cared for her husband for three months before his death on November 24, 1848. Martha and the family moved back to Philadelphia to live with her mother, soon after which her infant son died. Martha then turned to the care of her ailing mother, who after a protracted illness also died.

LIFE'S WORK

While tending sick family members, the young widow Coston had paid little attention to money matters. Medical and funeral expenses, coupled with her naïve trust in relatives and her husband's business associates, had drained her finances. Hoping to find something of value, Coston combed through her husband's papers. There she found notes on an uncompleted invention, one involving the use of coded combinations of colored fire to be used for remote communications at sea.

Coston remembered that her husband had tried making some test flares during his work at the Washington Navy Yard. After locating and retrieving the flares, she gave them to a trusted high-ranking naval officer for testing. While she awaited the results, illness claimed the life of yet another of her sons.

On the heels of this tragedy came the unwelcome news that her husband's flares had proved to be useless. However, Secretary of the Navy Isaac Toucey assured her that the concept was an excellent one. He encouraged her to perfect the invention, offering her use of the naval laboratory's personnel and resources. When those yielded no positive results, Toucey told Coston that, if she could find someone to make a working flare, the Navy would pay her expenses.

The young widow spent the next decade trying to realize her husband's concept, hiring and dismissing a series of chemists and conducting her own experiments. To carry out her husband's coded signaling plans, she needed to be able to produce three distinct, brilliant, and lasting pyrotechnic colors. She eventually managed to create intense, bright white and red flares, but a third color eluded her. (In a spirit of patriotism, she was striving for blue.)

A breakthrough came in August, 1858. America's top pyrotechnists were gathered in New York City to create a mammoth fireworks display celebrating the first transatlantic cable communication, a message sent by Queen Victoria to President James Buchanan. Among the convened fireworks experts, Coston found the technical

COSTON PYROTECHNIC NIGHT SIGNALS

Martha J. Coston's flares were metal cartridges packed with a proprietary chemical composition that burned with brilliant, distinct colors. The original standard set of Coston signals was made up of twelve pyrotechnic cartridges. Three would burn in a single color (red, white, or green), and six would burn in differing combinations of two of the colors; these flares represented numbers 1 through 9. The one flare including all three colors represented the number 0. Rounding out the set were a preparatory cartridge *P* (white-red-white) and an assent cartridge *A* (red-white-red). The cartridge cases were painted to indicate the color of the pyrotechnics.

To convey a message—for example, "cease fire"—the sender would set off the *P* flare, and the receiver would acknowledge readiness by responding with the *A* flare. Because the numeric code for "cease fire" was 3-1, the sender would then set off the cartridge corresponding to 3 (white then green) immediately followed by the cartridge representing 1 (white).

Users of the earliest Coston signals fitted the cartridge into a manual holder, ignited the flare by hand, and held it aloft until the flame was spent. By the early 1860's, a pistol-type holder had emerged (inventor unknown) that lit the cartridge by means of an exploding percussion cap. Coston's 1871 patented improvement to the original flare included a redesigned holder and a self-igniting outer casing for the cartridge. Twisting the handle and cartridge casing in opposite directions caused a built-in match to be struck, lighting the flare. Other improvements included elder son Henry Coston's aerial signaling system (patented in 1877), in which a pistol-type igniter and holder launched the pyrotechnics high in the air.

Before Coston's flares, ships at sea could communicate at a distance with other vessels or onshore personnel using a variety of coded signals involving flags, colored lanterns, rockets, or flashes from a fired pistol. What set the Coston flares apart was their effectiveness at night and under rainy, foggy, and smoky conditions; the ease with which their messages could be understood; and the distance at which they were effective (when ignited, the flares could be seen from ten or more miles away, depending on visibility conditions and the size of the flare used). Their resistance to spontaneous combustion made them safer than other, more unstable signaling pyrotechnics.

The flares proved themselves time and time again during the Civil War. Countless nighttime efforts to slip past Union blockades were foiled thanks to ship-to-ship communication via Coston flares. Battles were coordinated using the flares, notably the Union's successful and strategically significant January, 1865, attack on the Confederate garrison at Fort Fisher, North Carolina.

During and after the war, the flares aided search and rescue efforts. In December, 1862, when the ironclad warship USS *Monitor* sank in a storm off Cape Hatteras, Coston flares brought rescuers to the scene. The flares saved lives in unexpected ways, too: Coston's autobiography tells how Arctic explorers used theirs to chase wolves from their camp.

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know-how she needed. Within months, she had her third color (blue being prohibitively expensive, she settled for green) and a reliable, functioning flare.

Coston was granted U.S. Patent number 23,536 for her "Pyrotechnic Night Signals" in April, 1859. She filed as administrator for B. Franklin Coston, crediting her husband rather than claiming the invention as her own. (One of the witnesses was a J. Quincy Adams—possibly President John Quincy Adams's lawyer grandson, as the president himself had died over a decade earlier.) Coston was one of only five women to receive a patent in 1859, and the only one whose invention was of a nondomestic nature.

Later that year, she also obtained patents in England, France, the Netherlands, Austria, Denmark, Italy, and Sweden and sold three hundred trial flares to the U.S. Navy for approximately $5,000. Navy vessels equipped with the trial flares would make overwhelmingly favorable reports over the next two years on the invention's effectiveness.

Beginning in the summer of 1859, Coston paid extended visits to England and France to interest the navies of both countries in the use of her flares. She returned to the United States in early 1861, shortly before the presidential inauguration of Abraham Lincoln and the beginning of the Civil War. Lincoln's call that year for a blockade of all U.S. ports resulted in a pressing demand for the flares. Based on the success of the trial flares, Congress paid Coston $20,000 for rights to the patent for use by the Navy and contracted with her to produce the flares. She initially hired a manufacturer to fulfill the orders to her specifications, but in later years she and her sons took over the business of manufacturing the flares.

In January, 1863, Coston set sail for Europe, where she would spend the next several years marketing her invention while mingling with society, nobility, and royalty. In 1867, the French government (after a protracted but fruitless effort to reverse engineer the invention) purchased the rights from her to manufacture the flares for use by France's military. In June, 1871, Coston was granted a U.S. patent (number 115,935), this time under her own name, for a new invention: an improvement to the flares that enabled the user to ignite a Coston signal by twisting its handle.

Coston moved back to the United States in 1873, by which time Italy, Denmark, and the Netherlands had officially adopted the flares. America's Civil War had ended eight years earlier, and the Coston family's domestic marketing efforts turned to civilian use of the flares by passenger ships, yachts, the U.S. Merchant Marine, and the Life-Saving Service (later the Coast Guard).

Coston detailed her experiences as a wife, widow, inventor, and traveler in her 1886 autobiography *A Signal Success*. She died in 1904. The Coston Signal Company (renamed the Coston Supply Company in 1927) remained in operation at least until the mid-1980's.

IMPACT

Coston labored for years to bring her husband's idea to fruition. Her efforts yielded untold savings in lives and property. For more than a century, her flares were used around the world by military, civilian, and commercial watercraft in distress to call for aid. With the flares, onshore personnel warned ships away from hazardous conditions. Similar signaling devices inspired by Coston's flares are still in use today and are considered standard marine safety equipment.

Coston's well-timed success in perfecting the invention meant that the North entered the Civil War equipped with the new flares. Coston's signaling device may not have been the deciding factor in the war, but it certainly was a strategic advantage for the Union's naval forces, and the part it played in planning and executing battles may have helped to bring the war to a close that much sooner.

As a nineteenth century woman working in a traditionally male field, Coston encountered her share of resistance, and sometimes even overt hostility. Yet she persisted, determined to support herself and her family, contribute to her country's welfare, create a quality product, and earn a fair price for it. Her story was an inspiration for women entering the twentieth century, and it still inspires today.

—*Karen N. Kähler*

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See also: John Campbell; Nils Gustaf Dalén; John Harrison.

FREDERICK GARDNER COTTRELL

American chemist

Although electrochemists remember Cottrell best for the Cottrell equation, which is important in chronoamperometry (a measuring technique for electrochemical analysis), he is most famous for inventing the electrostatic precipitator for removing suspended particles from gases, thus abating smoke pollution from power plants and dust from cement kilns.

Born: January 10, 1877; Oakland, California
Died: November 16, 1948; Berkeley, California
Primary field: Chemistry
Primary invention: Electrostatic precipitator

EARLY LIFE

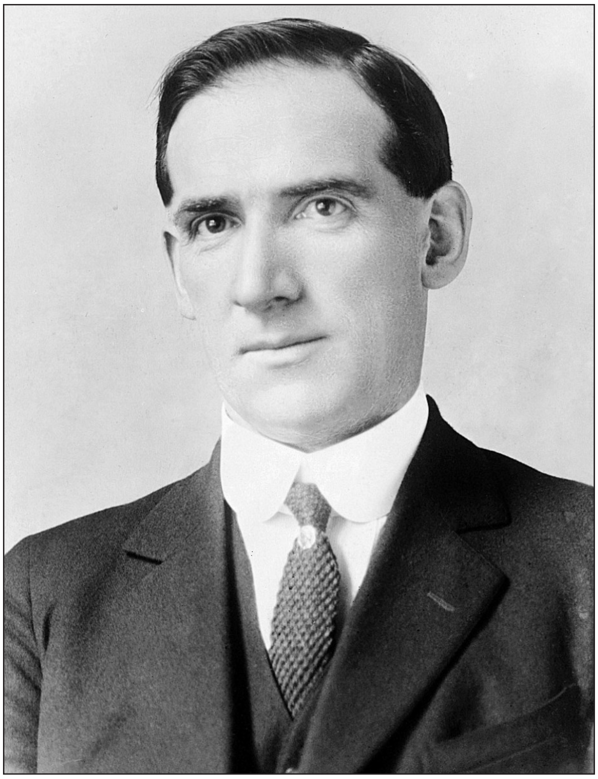
Frederick Gardner Cottrell was the son of Henry and Cynthia L. Durfee Cottrell, a *Mayflower* descendant. As a young boy, he was fascinated with photography, as was his father. With money earned from chores, he bought a small printing press and printed business cards for various services, including installing electric doorbells. He started a magazine about scientific progress, *Boy's Workshop*; one article on the deposition of dust by electrical aid was written when he was thirteen. He received his early education at the Horton School in Oakland, California, and after two years at Oakland High School, he passed the entrance examination into the University of California, Berkeley, from which he graduated in three years.

Before becoming a teacher at Oakland High School, Cottrell was an assistant to the professor of chemistry at the university. Living frugally and saving money from his teaching job and a weekend job as laboratory assistant at the university provided him the means to do postgraduate work in Germany at the University of Berlin and the University of Leipzig, where he earned his Ph.D. (summa cum laude). Upon his return to California, he joined the faculty at the University of California, Berkeley. In 1904, he married Jessie M. Fulton, whom he had met in a botany class in high school. During this time, Cottrell's father died, and his two children died in infancy.

LIFE'S WORK

After Cottrell's father died, he was left with several relatives to support, so without a definite plan, he turned to research in the hope of inventing something quickly in order to make money. One idea came to him on recalling problems reported by former classmates who had become miners. Miners, as well as manufacturers of cement, explosives, and chemicals, realized that dust, smoke, and vapor from kilns, furnaces, and smelting were damaging the environment up and down the West Coast. The filters available were ineffective, so Cottrell determined to find some new method to solve the problem. He remembered reading about an experiment by the English physicist Sir Oliver Lodge in which electrical precipitation had been used, although unsuccessfully. Nevertheless, applying the principle, Cottrell spent $20,000 and five years developing a precipitator that would remove more than 98 percent of the dust.

A large lead-smelting company whose existence was threatened with an injunction consulted Cottrell; within a few months, electrostatic precipitators were installed, and the company's problem was solved. The word spread, and other smelting plants consulted him, as did the Southern Pacific Railroad, which sought a way to re-



Frederick Gardner Cottrell. (Library of Congress)

The Electrostatic Precipitator

While trying to think of some invention that would enable him to gain funds sufficient to support relatives after his father died, Frederick Gardner Cottrell happened to recall hearing some former classmates who had become miners complaining about the damage being caused by smoke, dust, and vapor, and about the millions of dollars that firms were spending to settle lawsuits or to buy up large tracts of land to stop complaints of citizens in the area. He determined at that moment to devise a new method of dealing with the pollution. He also recalled reading about the work of an English physicist, Sir Oliver Lodge, who had tried unsuccessfully to clean the air using electrical precipitation. Applying the general principles of this earlier work, Cottrell spent five years and some $20,000 in developing a complicated machine that would remove over 98 percent of the pollutant.

A lead-smelting company that was being threatened with injunctions by area farmers heard of his invention and called Cottrell in; soon, similar firms everywhere were seeking Cottrell's help. Meanwhile, Cottrell was discovering other uses for his electrostatic precipitator. The Southern Pacific Railroad needed to find a way to remove emulsifying water from petroleum in the oil pipelines it operated. The same principle used in cleaning the air worked: a current was run through the emulsified oil, separating the water from the oil. His precipitator also proved effective in recovering one hundred tons of cement particles as well as reclaiming potash at a cement plant. The devices, also known as cottrells, are also used to enable power plants to burn pulverized coal without creating illegal levels of smoke emission, to reclaim gold and silver, to apply sand to an adhesive surface to make sandpaper, and to attract flock to a rubber base to make carpet.

While adaptations are necessary to address different problems, the electrostatic precipitator works by recognizing that fine droplets and solid particles in smoke, for example, are held in suspension by repelling electrical charges on their surfaces. The device neutralized the charges on a suspended material and causes it to precipitate.

The first patent for Cottrell's electrostatic precipitator was issued on August 11, 1908. The expense this device has saved in abating pollution and reclaiming various materials makes it invaluable. Companies that install cottrells find that they pay for themselves quickly in terms of the value of the materials that the precipitated solids are able to recover.

move emulsifying water from petroleum in the pipelines it operated. Cottrell was able to reclaim potash from cement particles in a cement plant. In 1907, he applied for a patent for his electrostatic precipitator, which came to be known simply as a "cottrell." Over time, the devices made it possible to burn coal without creating illegal levels of smoke emission, to reclaim large amounts of gold and silver for government mints, to apply sand to an adhesive surface to make sandpaper, to attract flock to a rubber base to make carpet, and to remove arsenic from sulfuric acid for a DuPont installation in California.

In 1911, Cottrell became chief physical chemist for the U.S. Bureau of Mines, and he advanced to the position of director in 1919. During his brief time in that position, he worked in World War I programs to develop processes by which nitrogen could be fixed for explosives and to distill helium from air for use in lighter-than-air craft. The following year, however, he became chairman of the Division of Chemistry and Chemical Technology of the National Research Council, while continuing as a consultant for the Bureau of Mines. Between 1922 and 1930, Cottrell served as director of the Fixed Nitrogen Research Laboratory of the U.S. Department of Agriculture.

Although financing the experiments that would result in the electrostatic precipitator had been a challenge, the profits from its manufacture could have made Cottrell a wealthy man. However, he felt that he should use some of the profit to support scientific research, so in 1912 he founded the Research Corporation with the help of Charles Walcott, then secretary of the Smithsonian Institution. The foundation was set up to receive income from his patents and those of other inventors; the funds were then distributed to university researchers in the physical sciences as seed money. Some successful recipients who were funded include Ernest Orlando Lawrence, who developed the cyclotron and was later awarded the Nobel Prize in Physics; Robert H. Goddard, a pioneer rocket scientist whose work laid the experimental foundation for rockets used in World War II and for modern spacecraft; Robert R. Williams, who, after turning his patents for the volume production of vitamin B_1 over to the foundation, saw the price of the vitamin reduced from ten dollars per gram to a few cents; and James Van Allen, who used a small grant to study radiation surrounding the earth, with the result that the Van Allen radiation belt he discovered became known worldwide.

While Cottrell downplayed the praise given him for choosing to help other scientists over gaining a personal fortune, numerous awards were conferred on him in recognition of his achievements. In 1919, he was awarded the Perkin Medal by the Society of Chemical Industry. The next year, the Chicago section of the American Chemical Society selected him to receive the Willard Gibbs Medal, given to eminent chemists whose work has enabled everyone to live more comfortably and to understand the world better. In 1927, the University of California conferred upon him an honorary LL.D. Two honors came his way in 1937: He was given the Gold Medal of the Mining and Metallurgical Society of America and the Washington Award, given by the Western Society of Engineers. The following year, he was the recipient of the Melville Prize Medal. In 1943, the American Society of Mechanical Engineers honored him with the Holly Medal. He also garnered the Medal of the American Institute of Chemists.

Cottrell was a member of numerous professional organizations and honor societies, including the National Academy of Sciences, the American Institute of Mining Engineers, the American Association for the Advancement of Science, and the American Electrochemical Society. He was inducted into Phi Beta Kappa, Sigma Xi, and Alpha Xi Sigma.

IMPACT

Cottrell was driven throughout his distinguished career by an energetic pioneering drive in physical chemistry and industrial engineering as well as by a strong and persistent sense of the social significance of scientific and engineering advances. He had a strong belief in the social responsibility of a scientist or engineer, and he held a strong and steadfast conviction about the intrinsic value and the human utility of research.

When Cottrell undertook to find a way to remove suspended particles from gases and thereby perform pollution abatement, a project at which an earlier scientist had been unsuccessful, he came up with a device that would later be found in industrial plants throughout the world. Considered to be an indispensable item because it can cleanse a factory's exhaust of dust and chemicals that otherwise would poison streams and crops and pollute the air, the electrostatic precipitator came to be known simply as a cottrell. If his electrostatic precipitator were his only major contribution to science and engineering, that would still have made him worthy of recognition, but many remember him best for his creation of the Research Corporation in 1912. He set up this foundation to receive his own patents as well as those of other public-spirited inventors. With the funds generated, he distributed seed money to university researchers in the physical sciences. The organization prefers to help young scientists who need funding for their first major projects. Cottrell himself said, "Bet on the youngsters. They are long shots, but many will pay off."

—*Victoria Price*

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See also: Meredith C. Gourdine; John Tyndall.

JACQUES COUSTEAU

French oceanographer and engineer

Cousteau gained the reputation as the most well-known underwater explorer in the world. He codeveloped the Aqua-Lung, an underwater breathing apparatus that supplied oxygen to divers, later modernized to today's scuba gear. He likewise invented a waterproof container for filming underwater, helped to start the first human undersea colonies, constructed jet-propelled submersibles for underwater observation, and designed a new wind-power system for boats.

Born: June 11, 1910; Saint-André-de-Cubzac, France
Died: June 25, 1997; Paris, France
Also known as: Jacques-Yves Cousteau (full name)
Primary field: Oceanography
Primary inventions: *Calypso* (ship); Aqua-Lung

EARLY LIFE

Jacques-Yves Cousteau (zhahk eev koo-STOH) was born in 1910 to Daniel and Elizabeth Duranthon Cousteau in a small town near Bordeaux, France. Cousteau's family traveled often in his youth, including overseas. During the summer of 1920, Cousteau and his brother were sent to camp at Harvey's Lake in Vermont while their father worked in New York City. One of the chores at the camp was to clean debris from the bottom of the lake near shore. This exercise not only helped improve Jacques's health but also gave him a lifelong love of underwater activity.

After being expelled from traditional high school, Cousteau was sent to a strict boarding school, where he graduated in 1929. In 1930, he gained entrance to the French Naval Academy at Brest. After graduation in 1933, he spent two years aboard a French naval cruiser. Returning to France in 1935, Cousteau decided to enroll in a naval aviation program in the hope of becoming a pilot. However, a 1936 car crash in which both of his arms were severely broken put an end to that dream. After months of recuperation, Cousteau was assigned to the navy's base at Toulon as a gunnery instructor. During the same year, he tested a pair of underwater goggles near the base. His utter fascination at what he saw changed his life, and he began to develop ideas for sustained exploration of underwater milieus.

LIFE'S WORK

During World War II, Cousteau served in the French Resistance against the occupying German army. In late 1942, he and French engineer Émile Gagnon invented the Aqua-Lung, a breathing apparatus that allowed divers to swim freely while being able to breath underwater. The device was valuable not only for underwater filming but also for inspecting and repairing ships and for removing enemy mines in the waters surrounding France. After the war, Cousteau showed a French admiral an underwater exploration film that had been made during the war. In 1946, the French navy placed Cousteau in charge of an assemblage, the Undersea Research Group, assigned to continue such investigation. From 1946 until Cousteau left the navy in 1949, he and his colleagues searched underwater caves, conducted physiological tests of the impact of deep diving, performed underwater archaeology by probing shipwrecks, and participated in the rescue of a bathyscaphe.

After leaving the navy, Cousteau sought to continue his undersea explorations. He acquired a former French minesweeping ship in 1950 and converted it for use by his diving team. The ship, named the *Calypso*, would be Cousteau's home away from home for much of the next forty years. In 1952, the Cousteau team discovered a sunken Roman cargo ship near Grand Congloué Island off the coast of France. The ship dated back to 230 B.C.E., making it the oldest ever uncovered up to that time. Subsequently, the *Calypso* and its crew studied marine life and environments in oceans (Atlantic, Pacific, and Indian), seas (Aegean and Red), and rivers (Amazon, Nile, Mississippi, and St. Lawrence). Cousteau recorded his findings on paper and film, which were later turned into books, documentaries, and television specials.

During the 1960's, Cousteau planned and implemented the Conshelf Project, which was designed to investigate the long-term effects of living under the ocean. The Cousteau team built three dome-shaped structures of various sizes as part of the project. Conshelf I, set up in the Mediterranean, housed two divers for a week in 1962. Conshelf II, built on the floor of the Red Sea, housed five divers for a month. Conshelf III, established off the coast of Nice, France, housed divers more than three hundred feet deep for a month.

Two other Cousteau inventions related directly to his explorations. In 1967, Cousteau launched two small submersibles created for underwater exploration. These vehicles, called Sea Fleas, permitted filming underwater and had mechanical arms for recovering objects. In 1980, Cousteau and two other Frenchmen designed a new engine system for ships that was partially based on wind power. Referred to as the Turbosail, the device furnished a renewable source of power while reducing reliance on oil-burning engines.

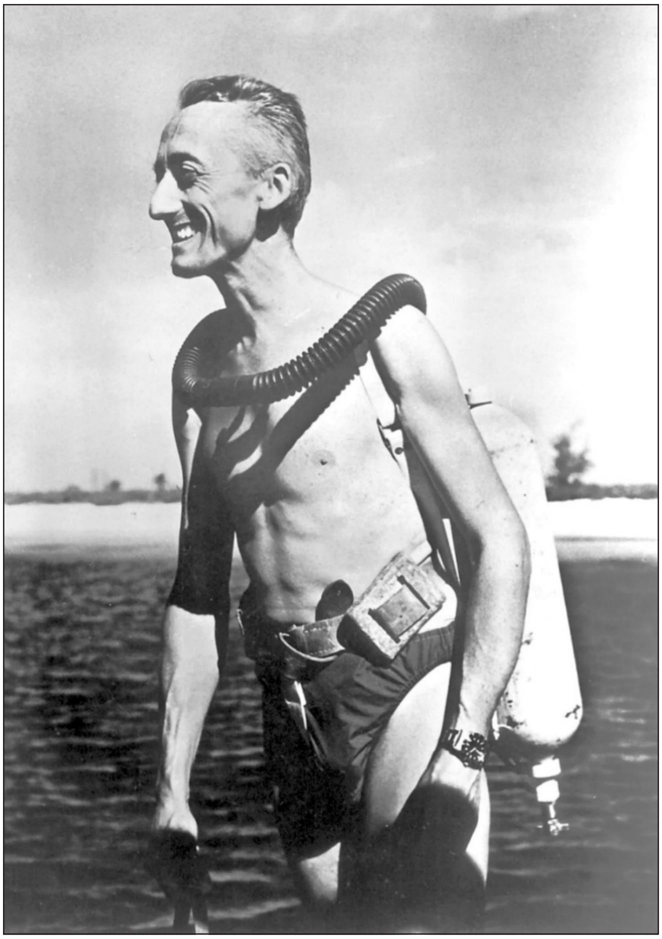
Cousteau used his influence to teach about the effects of pollution on the world's ecosystems. In doing so, he became an environmentalist and conservationist. For instance, in 1960 he led a protest against dumping radioactive waste in the sea. In 1973, he helped to establish the Cousteau Society for the Protection of Ocean Life. In 1990, Cousteau initiated a worldwide petition campaign to stop oil drilling and mining in Antarctica. Not only was the immediate campaign successful, but the world's nations also agreed to protect the area for the next half century. Because of his expertise and advocacy, Cousteau was invited to address the U.N. Conference on Environment and Development, which took place in Brazil in 1992.

Besides writing fifty books and producing two Academy Award-winning films, Cousteau was able to take advantage of the growing influence of television in order to educate and entertain a generation of underwater enthusiasts. As a result of a 1966 television special, Cousteau signed a contract with the American Broadcasting Company (ABC) in 1968 to produce a series, *The Undersea World of Jacques Cousteau*, which ran for eight seasons. In 1977, Cousteau produced a new series, *Cousteau Odyssey*, for the Public Broadcasting Service (PBS). In 1982, *The Cousteau Amazon* series premiered on Turner Broadcasting System. From 1985 through 1994, *Cousteau's Rediscovery of the World* was broadcast on American television. Overall, Cousteau and his team produced more than 120 television documentaries and garnered forty Emmy nominations.

Despite his success and notoriety, Cousteau encountered his share of heartache during his long career. During his team's deep-diving tests in the late 1940's, at least one close friend was killed as a result of carbon monoxide poisoning. In 1979, his youngest son, Philippe, was killed when his seaplane overturned and broke apart near Lisbon, Portugal. Cousteau's wife, Simone, died of cancer at age seventy-two in 1990. In January, 1996, the Cousteau team's beloved vessel, the *Calypso*, was rammed and sunk by a barge in Singapore. That same year, Cousteau prosecuted his son Jean-Michel over the use of the Cousteau name. Jacques Cousteau died in June, 1997, at eighty-seven.

IMPACT

During Cousteau's life, his work was attacked in certain quarters as nonscientific. That was somewhat ironic, given the alliance that the Cousteau team had with scientists who often came aboard the *Calypso*. Notwithstanding the latter criticism, Cousteau earned many national and international awards. In addition to several honorary degrees, he received a number of distinctions, among them the National Geographic Society Gold Medal, 1961; the Boston Museum of Science Bradford Prize, 1965; the Franklin Institute Potts Medal, 1970; the United Nations International Environmental Prize, 1977; the Lindbergh Award, 1982; the Bruno H. Schubert Foundation prize, 1983; the New York Zoological Society Gold Medal, 1985; the U.S. Presidential Medal of Freedom, 1985; the International Council of National Academy of Television Arts and Sciences Founder's Award, 1987; induction into the Television Hall of Fame, 1987; the National



Jacques Cousteau. (Library of Congress)

Geographic Society Centennial Award, 1988; induction into the French Academy, 1989; and the Third International Catalan Prize, 1991.

More than any scientist of his time, Cousteau exposed the effects of pollution on the world's waterways. The organization that he cofounded to preserve the environment, the Cousteau Society, has nearly 300,000 members and boasts branches in several nations. As of 2009, the Cousteau Society is busy turning the *Calypso* into a museum and raising funds for the construction of *Calypso II*. In addition to Cousteau's impact on the technical side of underwater exploration, his Aqua-Lung, as well as articles, books, and television series about his undersea exploration, increased public interest in recreational scuba diving.

Perhaps one measure of Cousteau's fame is how he is treated by popular culture. Countless authors and musicians have written and sung about Cousteau's exploits. For instance, American musician John Denver wrote the song "Calypso" as a tribute to the ship and its crew. The 1975 song reached number one on the *Billboard* charts.

—*Samuel B. Hoff*

THE *CALYPSO*

Previously used as a minesweeper during World War II, the *Calypso* was retooled for use by Jacques Cousteau and his crew pursuant to its purchase in 1950. The ship measured about 140 feet long and traveled at a maximum ten knots. It included an underwater observation chamber in the front of the ship, along with an engine room, a steering room, a radio room, a mess hall with a kitchen, and cabins for crew members to sleep in. The ship possessed sophisticated navigation devices, such as sonar and radar.

In addition to the diving and photography equipment, the *Calypso* had its own scientific laboratory. Crew members performed scientific experiments along with other duties and chores. The *Calypso* was essentially the main part of a fleet of equipment employed for ocean research. Other than the ship itself, the fleet encompassed a helicopter and several submersibles. In 1985, a new ship called the *Alcyone* joined *Calypso* on its voyages. The former ship was outfitted with the Turbosail engine system, which Cousteau designed with Professor Lucien Malavard and engineer Bertrand Charrier. The Turbosail system permitted ship operators to alternate between fuel oil and wind power as conditions warranted.

In 1996, the more-than-four-decades-old *Calypso* was accidentally holed and sunk by a barge in Singapore. For viewers of Cousteau's television series, "*Calypso*" had been synonymous with the name of its captain, who died the following year.

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See also: Harold E. Edgerton; Edwin Albert Link; Ruth Patrick.

JOSHUA LIONEL COWEN

American toy train manufacturer

Cowen did not invent the toy train, electric or otherwise, but his Lionel electric toy trains set the standard in the toy train market during the twentieth century and are a leading collectible of the twenty-first century.

Born: August 25, 1877; New York, New York
Died: September 8, 1965; Palm Beach, Florida
Primary field: Manufacturing
Primary invention: Lionel electric toy trains

EARLY LIFE

Joshua Lionel Cowen was born Joshua Lionel Cohen, but no biographer knows with certainty why he changed his name in 1910. Some have speculated that it was to avoid the widespread anti-Semitism in the American toy-making industry at that time, although Cowen never attempted to conceal his Jewish heritage. He was the eighth of nine children of Hyman Nathan and Rebecca Kantrowitz Cohen, who had immigrated to the United States shortly after the American Civil War. Cowen's father manufactured cloth caps, employing several workers, and later expanded into real estate and jewelry. The family was comfortable but not wealthy.

Mechanical devices fascinated Cowen, who built his first toy train at the age of seven when he attached a small steam engine to a wooden locomotive he had built himself. Unfortunately, the engine exploded and damaged the wallpaper in his family's kitchen. Cowen attended Elementary School Number One in lower Manhattan and the Peter Cooper Institute for high school, where he studied technical subjects. He entered the City College of New York in 1893 but quickly dropped out. He then enrolled at Columbia University but left after one semester.

Cowen got his first job at the age of fourteen working in a trade magazine office and worked at dry-cell battery manufacturer Henner and Anderson from 1896 to 1897. Then he assembled battery-powered lamps for the Acme Electric Lamp Company.

Cowen met Cecelia Liberman in 1902 and married her in 1904. They had two children, Lawrence and Isabel. Cecelia died in 1946, and Cowen married Lillian Appel Herman three years later.

LIFE'S WORK

Cowen filed his first patent in 1899 for an ignition device for photographer's flash powder. The igniter used dry-cell batteries to heat a wire fuse. The U.S. Navy contracted with him to build twenty-four thousand of the devices to use as detonators for mines. Cowen filed his second patent in 1900 for an electric explosive fuse that consisted of a cardboard tube packed with a flammable chemical through which wires passed to provide the heat for ignition.

Cowen and a partner formed the Lionel Manufac-

1901
Electrical Novelties and Appliances for BOYS
Oh!

Joshua Lionel Cowen is honored with a display at the Lionel headquarters in Chesterfield Township, Michigan. Cowen created his first electric toy train, the Electric Express, in 1901. (AP/Wide World Photos)

Lionel's Electric Toy Trains

The first electric toy trains were manufactured by the Carlisle and Finch Company in 1893. They ran on metal strips and were powered by two wet-cell batteries. Joshua Lionel Cowen's first train, the Electric Express, ran on four dry-cell batteries. By 1906, Cowen had developed a transformer that connected the tracks to wall outlets and reduced the outlet's 110 volts to 20, eliminating the need for batteries. Originally, one track carried the positive charge, and the other the negative. Another of Cowen's innovations was the three-track system in which the center track was positive and the two outside ones were negative. This system was less susceptible to short circuits. The tracks of Cowen's earliest trains had a gauge of $2\frac{7}{8}$ inches, but for many years the less expensive Lionel trains used a $1\frac{1}{4}$-inch gauge, called the "O" gauge, and the more expensive ones a $2\frac{1}{8}$-inch gauge, called the "standard" gauge.

Lionel's leading standard-gauge train for many years was the Pullman Deluxe. The base system was a No. 42 engine and three passenger cars. Introduced in 1912, it originally cost $62.50. For another $12.50, the buyer could substitute engine No. 54, which was finished in brass and nickel. In 1921, a second motor was added to the No. 42 so that it could pull more cars. By 1929, the Transcontinental Limited stretched nine feet and cost $110, more than a used car in good condition. However, freight trains were more popular overall, because the purchaser could add milk, cattle, crane, flat, oil, and other cars, and each one came with a caboose. Finally, Lionel sold accessories, such as bridges, tunnels, street lamps, conveyors, culverts, newsstands, crossing gates, houses, water towers, oil derricks, gantry cranes, barrel loaders, ice depots, freight sheds, floodlight towers, signal towers, train depots, fueling stations, artificial grass, artificial coal, coal elevators, forklifts, sawmills, and miniature people.

For the largest layouts, the No. 840 Power Station was available. Besides looking like a power station, it contained two transformers and six electrical switches. Among Lionel's later innovations were a "chugger" sound effect in 1933, a whistle in 1935, automatic couplers in 1945, smoking trains in 1946, and magnetic traction in 1950.

turing Company in 1900 with the intention of selling small electric devices. In 1901, Cowen invented a battery-powered portable electric fan. Unfortunately, it circulated air poorly. However, Cowen used the fan's motor to power his first electric train, the Electric Express. Essentially a cigar box on wheels, it was sold not as a toy but rather as a department store window advertisement. To everyone's surprise, the store's customers were more interested in the train than what it was advertising, so the store ordered more for resale. Cowen's second train, the City Hall Park, appeared in 1902, the same year as the first Lionel catalog. The City Hall Park was the first switch to allow figure-eight track configurations and the first accessory, a two-foot-long suspension bridge. By 1906, he was marketing the trains exclusively as toys. Annual sales grew from $22,000 in 1907 to $839,000 in 1921. In 1918, the Lionel Corporation was formed with Cowen at the head, but from then on he spent most of his time on marketing rather than inventing.

During World War I, Lionel manufactured compasses and other navigational equipment, but he returned to making toys after Germany surrendered. In 1929, Cowen bought control of Ives, one of his leading competitors, and intended to take early retirement. However, the Great Depression forced a change of plans. First, the stock market crash reduced the funds available for his retirement. Second, Lionel's sales declined for the first time, from $2.2 million in 1929 to $1.9 million in 1930, and in 1931 Lionel lost money for the first time. By 1934, Lionel had to go into receivership, although Cowen remained as head of the corporation. Finally, Cowen was a member of the board of directors of the Bank of the United States, which failed in 1930, and New York's state superintendent of banks required him to pay $850,000 out of his own money to make restitution to account holders.

Lionel returned to profitability in 1934 with two products. First, it licensed Mickey and Minnie Mouse from Walt Disney for a windup handcar. Lionel sold 253,000 of the one-dollar toys by Christmas and took orders for an additional 100,000 that were delivered in 1935. The other product was the Union Pacific M-10000 train, which retailed for $19.50 and became the best-selling Lionel train up to that time. Lionel came out of receivership in 1935 and went public in 1937.

Lionel manufactured compasses, navigational instruments, and percussion primers during World War II. Although the corporation manufactured no toy trains from 1942 to 1945, sales rose to $7.2 million in 1943 from military contracts alone. After the war, Cowen passed responsibility for day-to-day operations to his son, Lawrence, but stayed on as chairman of the board. In 1946, sales reached $10 million a year; they peaked at $32.9 million in 1953, when Lionel was the largest toy manufacturer in the world. Two-thirds of the toy trains sold in the United States and 62 percent of those in foreign countries were Lionel trains. However, annual sales dropped to $14.4 million by 1958, because the toy market changed. Most American households now owned a television, and airplanes and cars had overtaken trains as the most popular toys for boys. While Lionel manufactured both kinds of toys, it was not a leader in either category.

Lionel attempted to diversify, but it consistently guessed wrong in choosing new products, including an electric cattle guard, a toy chemistry set, a toy construction set, fishing reels, and a 3-D camera. The last product lost hundreds of thousands of dollars, because the 3-D camera market turned out to be a fad, and the fishing reels, while initially profitable, eventually lost market share to inexpensive Japanese imports. Under pressure from stockholders, Cowen resigned as chairman of Lionel in 1958 and sold his Lionel shares in 1959.

IMPACT

The U.S. Postal Service included the 1929 Lionel catalog cover in its 1998 Celebrate the Century series of stamps. In 1999, the A&E cable channel produced a show about the top ten toys of the twentieth century in which it ranked Lionel toy trains as number four, behind the yo-yo, crayons, and Barbie dolls.

Cowen's marketing had the negative impact of reinforcing sexual stereotypes, because he marketed trains exclusively to boys. One of the few toys for girls that Lionel ever manufactured was an operational electric range so that girls could learn to become housewives. In 1957, Lionel finally attempted to market a train to girls, called the Lady Lionel, but its pastel colors, including a pink locomotive, did not appeal to girls any more than it did to boys and contributed to Cowen's departure. So few sets were sold that they are especially valuable in the twenty-first century as collectibles.

Lionel trains are still being manufactured in the twenty-first century, but it is a completely different market. Toy trains, which can cost more than $1,000, are mostly owned by adult hobbyists rather than preadolescent boys. The Train Collectors Association, founded in 1954, boasts of a membership of more than thirty thousand. *Classic Toy Trains*, the leading magazine of the hobby, has a circulation of seventy thousand and found from a year 2000 survey of subscribers that their average age was fifty-four. Richard Kughn, who owned Lionel from 1986 to 1996, was a typical hobbyist in that he remembered receiving a Lionel train for Christmas when he was nine years old in 1938. In other words, the twenty-first century market for toy trains is a niche, rather than a mass, market.

—*Thomas R. Feller*

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See also: Edwin Binney; Beulah Louise Henry.

SEYMOUR CRAY

American computer designer and electrical engineer

Known as the "father of supercomputing," Cray created the world's fastest computers in the 1960's and early 1970's. His machines were made for a small group of scientific users but became prototypes for advances in computing that eventually became mainstream.

Born: September 28, 1925; Chippewa Falls, Wisconsin
Died: October 5, 1996; Colorado Springs, Colorado
Also known as: Seymour Roger Cray (full name)
Primary fields: Computer science; electronics and electrical engineering
Primary invention: 6600 computer

EARLY LIFE

Seymour Roger Cray was the son of Seymour and Lillian Cray. The elder Seymour was a civil engineer who worked for the town of Chippewa Falls, Wisconsin. The younger Seymour showed an interest in science and technology at a very early age. He ran wires though the family home so that he and his younger sister Carol could communicate with Morse code. He was also interested in photography, and he was allowed to experiment with electronics and chemistry at home. In high school, he excelled in science. After high school, he entered the Army and worked with electronics and radio equipment in Europe and the Philippines during World War II.

After the war, he attended the University of Wisconsin and then the University of Minnesota, where he earned a bachelor's degree in electrical engineering in 1950 and a master's degree in applied mathematics in 1951. During his college years, he worked as an electronics repairman. He developed a unique combination of skills, and his deep familiarity and practical experience with electronics, when augmented with advanced studies in mathematics, gave him an ideal background for what would become his life's work: the design of logic circuits and other hardware for the world's most powerful computers. Fortunately for Cray, he soon found himself in a perfect environment for learning almost everything that had been accomplished up to that time in terms of computer engineering. One of his teachers at the university recommended that he apply at an engineering firm that was located in a nearby factory that had been used to build wooden gliders for the invasion of Normandy.

LIFE'S WORK

The firm was Engineering Research Associates (ERA), founded by William Norris and other cryptographers who had served in the U.S. Navy. They developed mechanical devices to break the Germans' Enigma code, thus allowing the Navy to find and destroy Nazi U-boats. In their postwar facility at St. Paul, Minnesota, they continued their work as civilians, but their primary customer was the Navy, and the nature of their work was kept secret from the general public. When Cray joined ERA in 1950, they had recently created a revolutionary new technology, the first computer-memory storage system, consisting of pieces of magnetic tape glued to a large rotating metal drum. Cray quickly immersed himself in their work, and along with other newly hired engineers, he was given classes in Boolean algebra and other relevant topics. He soon distinguished himself as an outstanding new talent and rose quickly within ERA, where he helped to design one of the first scientific computers, the ERA 1103, and remained with this group though various corporate changes, including their work for Sperry Rand's UNIVAC Division.

In 1958, Cray joined William Norris, who had left Sperry Rand to become the chief executive officer of Control Data Corporation (CDC), a new company that carried on the development of scientific computers. He began working on new designs, with transistors replacing vacuum tubes, resulting in the CDC 1604 (1960), the most powerful computer in the world at the time. Most of these machines, which cost millions of dollars to produce, were sold to government agencies and scientific research labs such as the Lawrence Livermore National Laboratory in California. However, the commercial success of these products became increasingly distracting for Cray, who required long stretches of uninterrupted time to concentrate on his work. Since Cray was the director of engineering, his request to have his own facility in a more secluded environment was granted by Norris. Chippewa Falls, Wisconsin, Cray's own hometown, became the new location, enabling him to live next door to his lab and to set his own hours. Cray continued to top his own world records for processing speed with each new product. The CDC 6600 computer, introduced in 1964, used revolutionary new designs in processor architecture, peripherals, and cooling. It was utilized for modeling nuclear reactions and other demanding tasks. His next computer, the CDC 7600, was over five times faster.

THE 6600 COMPUTER

Supervised by Seymour Cray, with system design by James E. Thornton, the CDC 6600 was the second major product to come from Cray's work for the Control Data Corporation (CDC). Building on the success of the CDC 1604, Cray continued using transistors for logic gates but switched from germanium to silicon, to overcome speed limitations. Another speed-boosting innovation was Cray's use of multiple processors: The 6600's central processor was freed from input and output tasks, which were handled by external processors. Its 60-bit word length could accommodate very large pieces of data. The central processor itself comprised ten parallel units that were each tuned for specific types of operations and that could engage in simplified components of a complex problem. The central processor was housed in an aluminum frame shaped like a plus sign when viewed from above, and there was space in the center for the thousands of wires, which were cut exactly to their minimum possible lengths in order to reduce latency.

The main chassis of the machine was about seven feet tall, with each of its four arms extending out six feet from the center. Instead of switches and lights, operators could use the machine with a keyboard and a pair of CRT monitors, which provided status displays. These peripherals connected to another external processor, which translated the data back and forth between the central processor and the communication interfaces. Another innovative aspect of the machine was its cooling system. Instead of fans, the machine was cooled by Freon gas circulating through coils, somewhat like a household refrigerator. A complete 6600 system with peripherals cost $6 million.

First introduced in 1964, the 6600 was about ten times faster than anything else available at the time. The machine was regarded by many as the first supercomputer. Optimized for the rapid floating-point processing required in scientific applications, the 6600 could reach three million instructions per second (MIPS). The supercomputer stimulated the development of operating system and compiler software so that customers, primarily government agencies, could harness the computer's power for practical use. Cray, already eager to make the 6600 obsolete by developing an even faster computer, was more interested in the speed and power of the processors, and other team members worked on the software.

The development of peripherals also was stimulated by the 6600. In addition to the monitor and keyboard interfaces, CDC developed a disk drive for more rapid storage and retrieval of data, replacing the magnetic drums used in previous computers. These new kinds of peripherals eventually became standard in computer systems. The parallel processing architecture of the 6600, in which computations were divided into simpler tasks for greater speed in execution, influenced the development of reduced instruction set computing (RISC) processors.

It used an instruction pipeline, so that incoming data could enter the processor while a previous instruction was still being executed. From approximately 1969 to 1975, this was the fastest computer, although it was not as profitable for CDC as its predecessor.

In 1972, Cray left CDC with several other employees and started his own company, Cray Research, on the same property in Chippewa Falls. He introduced the Cray-1, which used another of his innovations, vector processing, which increased speed by working with long arrays (lists) of numbers at once. Los Alamos National Laboratory was given the first preview edition of a Cray-1 in 1976, and the National Center for Atmospheric Research purchased one for more than $8 million. More than one hundred Cray-1 computers were sold. In 1980, Cray resigned from Cray Research and moved to Colorado Springs, Colorado. He eventually formed another company, Cray Computer Corporation, and introduced the Cray-3, which used semiconductors made of gallium arsinide. Although innovative, this product was not commercially successful, and Cray started another company, SRC Computers. Cray and his staff began work on a new computer using the massively parallel architecture that was proving fruitful for other researchers, but he was in a car accident on September 22, 1996, and died of his injuries two weeks later.

IMPACT

While the term "supercomputer" was redefined by each successive product that his companies released, Cray made many specific contributions in the course of his lifelong pursuit of processing speed and efficiency. Among these contributions are the concept of multithreading (introduced with the CDC 6600's ten independent processor states), the use of vectors as an architecture component, the simplification of processing instructions (a forerunner of reduced instruction set computing, or RISC, architecture), miniaturization of essential hardware (primarily in the transition from vacuum tubes to transistors and printed circuits), and cooling systems (with M. Dean Roush at CDC).

Along with their insights and creativity as engineers, Cray and his colleagues influenced the culture of research and development in computing. With relatively small teams of dedicated and talented people, and relatively meager resources, Cray competed successfully against much larger companies. He became almost legendary by rejecting corporate formalities, bureaucratic time consumption, and petty politics in favor of concentration, focus, and productivity.

Cray's supercomputers gave American scientists the ability to simulate nuclear explosions, helping to provide deterrence during the Cold War years while avoiding the physical and geopolitical dangers of actual detonations. The supercomputers contributed to rapid growth and development in computer hardware and software, leading in turn to one of the most radical transformations in human culture at the turn of the century.

—*John E. Myers*

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See also: John Vincent Atanasoff; Walter H. Brattain; Jack St. Clair Kilby; Robert Norton Noyce; William Shockley.

BARTOLOMEO CRISTOFORI

Italian engineer

A musical-instrument maker famous for his ingenuity, Cristofori set out to design a new instrument by improving the sound and mechanism of the harpsichord. He is credited with having invented the piano in Florence around 1700.

Born: May 4, 1655; Padua, Republic of Venice (now in Italy)
Died: January 27, 1732; Florence (now in Italy)
Also known as: Bartolomeo di Francesco Cristofori (full name); Bartolomeo Christofani; Bartolomeo Cristofali
Primary field: Music
Primary invention: Piano

EARLY LIFE

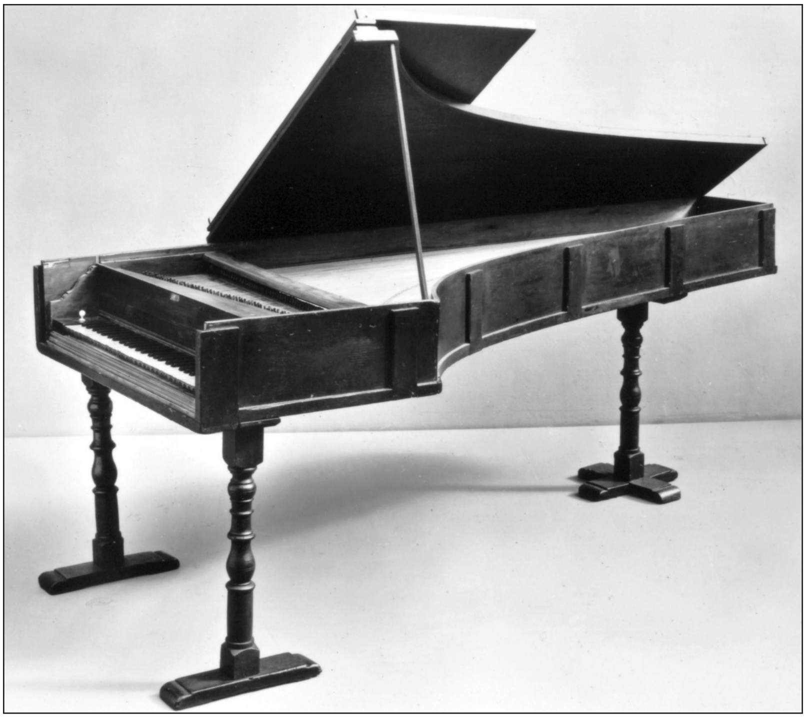
Bartolomeo Cristofori (bahr-toh-loh-MEH-oh krihs-TOH-foh-ree) was born to Francesco Cristofori and Laura Papafava in Padua in the Republic of Venice in 1655. He was christened in the parish of San Luca two days later, and his godparents were Camillo Chinoni and Pani Lina, maid to Lady Laura Papafava. Cristofori remained quite close to his mother's family, as is confirmed by a reference to a Roberto Papafava in Cristofori's second will. The name also occurs in one of Cristofori's letters sent from Florence in May, 1693.

Almost nothing is known of Cristofori's family life and his early years in Padua except that he had a younger brother, Pietro Filippo, whose christening record dating to May, 1657, proves that the family surname was Cristofori, and not Christofani or Cristofali, as Cristofori has at times been referred to. Even though there is no record of where his workshop was located, in his hometown Cristofori must have acquired considerable notoriety as an instrument maker. Indeed, while traveling to Venice to attend the carnival in 1688, Prince Ferdinando de' Medici, a humanist, patron, and lover of music, stopped at Padua and decided to recruit Cristofori, who agreed to the appointment at a salary of twelve scudi per month. A young man of thirty-three, Cristofori moved to the court of Ferdinando in Florence in May of that year and lodged and worked as harpsichord maker for the prince in the Galleria dei Lavori of the Uffizi.

LIFE'S WORK

Cristofori's activity as harpsichord maker at the court is well recorded, partly thanks to the many bills Cristofori submitted to his employer. It is known that on August 15, 1690, he was paid 1,036 lire for an oval spinet (a harpsichord with the longest strings in the middle of the case). This and other instruments built by Cristofori in the 1690's (for example, an upright harpsichord currently held in the museum of the Luigi Cherubini conservatory in Florence) are all documented in an inventory, dated to 1700, and show Cristofori's versatility as instrument maker.

The above-mentioned inventory also alludes to "a large *Arpicembalo* [harp-harpsichord] by Bartolomeo Cristofori, of new invention, that produces soft and



A grand piano made by the Italian harpsichord maker Bartolomeo Cristofori in 1720. (The Granger Collection, New York) loud." This is the first reference to the piano, on which Cristofori had been working since 1698. The limitations of Cristofori's piano were, however, all too obvious. Rather expensive to make, the instrument had unsophisticated hammer heads, and its range was a mere four octaves. All this meant that news of its existence did not spread rapidly, and only in 1711 did Francesco Scipione Maffei report on the new invention, which the Italian scholar had been able to examine two years earlier. In an article published in the *Giornale de'letterati d'Italia* of Venice, Maffei provided a thorough description of the new instrument illustrated with a diagram of the mechanism. Though he acknowledged that the sound of the piano was felt to be too soft and dull, Maffei recognized the importance of Cristofori's new instrument. He further reported that, by 1711, Cristofori had already built three pianos.

Cristofori was then at the peak of his career when his patron Ferdinando died on October 30, 1713. There is evidence that Cristofori continued to work for the prince's father, Cosimo III, and not merely as custodian of Cosimo's musical collection—as it is very often wrongly believed—but as instrument maker, or *strumentaio*. Proof of Cristofori's continuing activity after Prince Ferdinando's death is given by an inventory of the instruments owned by the Florentine court, dated 1732, which shows the steps taken by Cristofori to enlarge the musical collection of the Medici. The three surviving pianos built by Cristofori in 1720, 1722, and 1726—all signed by "Bartolomeo Cristofori of Padua, inventor," as a Latin inscription proudly proclaims—show that he endeavored to improve the quality of his pianos and confirm that Cristofori was active until practically the end of his life. In his last years, Cristofori owned houses in Florence, first in San Remigio and subsequently in San Iacopo tra' Fossi, both locations not far from the Uffizi. The only known portrait of Cristofori also dates from his Florentine period. Purchased by G. Schünemann for a Berlin museum in 1934 but destroyed during the course of World War II, it was painted in 1726 and portrays the inventor standing next to a piano against the backdrop of the city of Florence. Apart from the above-mentioned pianos, a total of six surviving instruments (oval spinets, harpsichords, and a double bass) are attributed to Cristofori. They are all held in museums across Europe and the United States.

Toward the end of his life, Cristofori wrote two wills. In the first, dated January 24, 1728, he bequeathed all his possessions to one of his most conspicuous pupils, Giovanni Ferrini, famous for making a harpsichord once owned by Elisabetta Farnese, queen of Spain. A second will superseding the first followed on March 23, 1729. In it, Cristofori bequeathed his possessions to

THE PIANO

At times classified as both a percussion instrument and a string instrument, the piano is played by means of a keyboard instrument that produces sound by striking strings with felt hammers. The hammers immediately rebound, allowing the strings to continue vibrating at their resonant frequency. These vibrations are transmitted through a bridge to a soundboard that amplifies them. Modern pianos come in two basic configurations: the grand piano and the upright piano. Grand pianos have the frame and strings placed horizontally, with the strings extending away from the keyboard.

Despite its relatively recent invention at the beginning of the eighteenth century, the piano has had a rather eventful history since Bartolomeo Cristofori's days. The new instrument remained practically unknown until Francesco Scipione Maffei's encomiastic article inspired the next generation of piano builders, who rapidly appropriated Cristofori's invention. Except for Gottfried Silbermann's prototype, in which the instrument was equipped with a forerunner of the modern damper pedal, all designs were, however, virtually direct copies of Cristofori's original piano. Between 1790 and 1860, the piano underwent considerable changes that led to the modern form of the instrument. It became more robust, its sound acquired more power, and its tonal range reached the seven or more octaves found on modern pianos. Other technical innovations included the use of a strong iron frame against the force of string tension, as well as the use of felt hammer coverings instead of layered leather hammers.

Throughout the nineteenth century, the piano repertoire expanded considerably, and Cristofori's invention became one of the most familiar musical instruments of the time. Its versatility was explored by renowned piano composers such as Ludwig van Beethoven, Frédéric Chopin, and Franz Liszt, whose music was to some extent also determined by continuing technical innovations on the instrument. As an example, the double escapement action was invented in 1821. This device, which allows a note to be repeated even if the key has not reached its maximum vertical position, facilitates rapid playing. Modern upright and grand pianos attained their present forms by the end of the nineteenth century. Improvements and lower costs made the piano aptly suited not only for public concerts but also for domestic use and solo performance.

Anna and Margherita del Mela—sisters of Domenico del Mela, builder of the first upright piano—who had assisted him during his illnesses, and to his niece Laura, daughter of Elisabetta Cristofori. Cristofori died in Florence on January 27, 1732, and was buried in the cemetery of Santa Croce. On the inventor's death record in the church of San Iacopo tra' Fossi (demolished in 1847), the date of his death reads instead "1731" because the document follows the Florentine calendar in which the year began on March 25, thus causing an apparent one-year discrepancy for some dates. Among Cristofori's Italian pupils, aside from Ferrini, were Gerolamo da Firenze and Gherardo da Padova. Neither was, however, able to match the skills of his master. More talented were instead the German C. G. Schröter and Gottfried Silbermann.

IMPACT

Irrespective of whether Cristofori was fully aware of earlier attempts to make keyboard instruments with struck strings, he was the first person to design the modern piano as it is now known. According to his contemporary witnesses, the new instrument, made of cypress wood, would improve the quality of the harpsichord, "which does not wholly convey human feelings." Building on his expertise as harpsichord maker, Cristofori succeeded in designing a piano in which the hammers strike the strings but do not remain in contact with them because this would dampen their vibrations. Although Cristofori's piano was made with thin strings, it was louder and more powerful than the harpsichord. Cristofori continued to improve the quality of his pianos until the end of his life.

In spite of his major achievement, Cristofori's reputation went into eclipse shortly after his death. Paradoxically, Maffei's journal article of 1711 contributed to Cristofori's obscurity. Translated into Latin and published in Joachim Adlung's *Musica mechanica organoedi* (1767; music for organ), Maffei's piece inspired the German Gottfried Silbermann to build a piano that overshadowed Cristofori's work. For over one hundred years, Silbermann was credited with the invention of the piano until scholars working at the turn of the twentieth century (most notably Leo Puliti and A. Kraus) finally corrected this error.

—*Alejandro Coroleu*

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See also: Emile Berliner; Hugh Le Caine; Leonardo da Vinci; Robert Moog; Charles Wheatstone.

SIR WILLIAM CROOKES

English physicist

Crookes discovered the element thallium and greatly improved the technique used to produce a vacuum in the glass Crookes tube, the forerunner of the television tube. He used the Crookes tube to discover many of the properties of cathode rays, and these studies led directly to discoveries by others, including X rays and electrons.

Born: June 17, 1832; London, England
Died: April 4, 1919; London, England
Primary fields: Chemistry; physics
Primary inventions: Spinthariscope; vacuum tube

EARLY LIFE

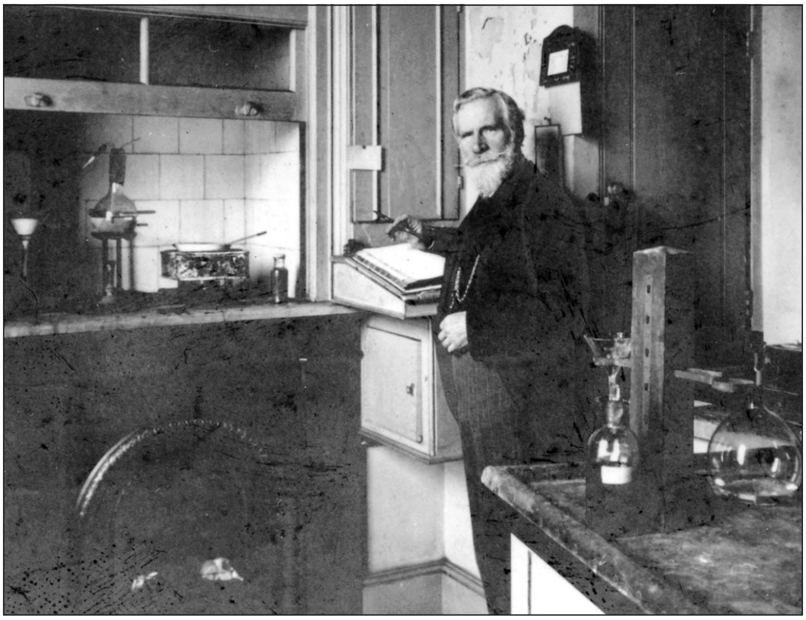
William Crookes (krooks) was the oldest son of sixteen children born to Joseph Crookes and his second wife, Mary Scott. Joseph was a prosperous tailor who also did well in real estate investments. Crookes left school at the age of fifteen and entered the Royal College of Chemistry in London. There he became an assistant to the famous scientist August Wilhelm von Hofmann. Working with Hofmann, Crookes became a meticulous and accomplished experimentalist. Hofmann introduced him to several well-known scientists, including Michael Faraday, who seems to have been Crookes's ideal. They were much alike; both Faraday and Crookes were brilliant lecturers and experimentalists, but both had to depend on others for advanced mathematics.

In 1854, friends aided Crookes's appointment as superintendent of the Meteorological Department at Radcliffe College, England, and in 1855 he taught chemistry at the College of Science at Chester. He moved into a fine house in London in 1856 (aided by a handsome inheritance from his father). He had a laboratory built into his home and worked as a chemical consultant, devising useful processes such as using sodium amalgamation for gold extraction, utilizing sewage and animal refuse, developing a chemical water-analysis scheme, promoting the use of carbolic acid in halting a cattle plague, and designing electric light bulbs. None of his commercial processes was more than modestly successful, but his house was the first in England to have electric lights. Also in 1856, he married Ellen Humphry of Darlington. They eventually had ten children, seven of whom survived early childhood; one of the survivors died at age thirteen.

LIFE'S WORK

In addition to his other ventures, Crookes edited several photographic and scientific journals. The most important of these was the *Chemical News*, which he founded in 1859 and for which he served as editor and proprietor until his death. He kept abreast of the latest advances in chemistry by publishing them in the magazine. Spectroscopy was invented in 1860, and it immediately drew Crookes's attention. It involved heating a material to incandescence and examining the light it emitted using a slit, lenses, and a prism. Light from the glowing sample passed through the slit, then the lenses focused that light onto the prism, which separated the light into rainbow patterns of variously colored slit images. These patterns of bright lines separated by dark spaces were different for different elements and therefore could be used to identify the elements present. This is the essence of spectroscopy.

Crookes had previously worked



Sir William Crookes in 1900. (Library of Congress) with selenium ores, so in 1861 he explored them spectroscopically. He soon noticed a bright green line that belonged to no known element. He named the new element "thallium," from the Greek *thallos*, "green twig." Although Crookes was able to refine only a tiny bit of thallium, he is credited with having discovered this element. He wanted to establish a very accurate weight for thallium, so he began to weigh small amounts in a vacuum. In the process, Crookes developed a method for obtaining a pressure one million times less than atmospheric pressure.

While weighing masses in a vacuum, Crookes found that some objects seemed to weigh slightly more warm than cold. Since these objects were in a vacuum, buoyancy effects could not account for this. He thought that light falling on an object might exert a very small force on it, or perhaps the infrared waves radiated by an object at room temperature might affect its weight. Crookes set about exploring this idea. He placed a small windmill with four sails, or vanes, inside a glass sphere and evacuated the air. With a needle for a pivot, the windmill turned with very little friction. One side of each vane was darkened with soot, while the other side remained a light color. He had expected that light falling on and being reflected from the bright side of the vanes would make them move away from the light, but they did not. Instead, the dark sides rotated away from the light. Crookes called his device a radiometer.

The radiometer provoked much discussion then, and it remains a popular scientific toy today. It can often be seen in the windows of novelty shops with its windmill spinning merrily in the sunlight. It turns out that the pressure of light is far too small to cause it to spin. Instead, residual air molecules clinging to the vanes are heated by the energy absorbed by the dark side of the vanes until they have enough energy to break free. As they break free, they give a minute kick to the vane, causing the dark side to rotate away from the light. Even lacking a full understanding of how it worked, Crookes used the radiometer to confirm a prediction by James Clerk Maxwell that the viscosity (resistance to flow) of a gas is independent of pressure except at very low pressures.

The next subject to capture Crookes's attention was the cathode rays in a Crookes tube. Crookes did not invent the tube, but his experiments with it were so remarkable that his name became forever associated with it. A Crookes tube is a glass tube with a volume of about a liter. Electrodes are placed in both ends, which are sealed. The air is sucked out, and a high voltage is applied to the electrodes. Cathode rays then stream from the negative electrode (called the cathode). Crookes showed that these cathode rays are a stream of particles because an object casts a crisp shadow when placed partially in the beam's path. (Electromagnetic waves would have bent somewhat into the shadow region.) Crookes found that they are negatively charged particles because they are deflected with a magnet. He speculated that the particles were negative gas ions.

Crookes was also involved in the study of radioactiv-

THE SPINTHARISCOPE

In 1903, William Crookes observed the fluorescence of a zinc sulfide screen as alpha particles from radium struck it. The three kinds of radiation known at the time to be emitted by radioactive elements such as radium had been named alpha, beta, and gamma (the first three letters of the Greek alphabet). Although not known until five years later, alpha particles are helium-4 nuclei (two protons bound together with two neutrons). Each alpha particle striking a zinc sulfide molecule produced a flash of light, a scintillation. When Crookes examined the screen under a microscope, he could see the individual scintillations. This was the first radiation detector that could detect individual events. Photographic film, for example, recorded only the combined effects of billions of billions of events.

Crookes took a small brass tube and placed a zinc sulfide screen at one end and a lens at the other end. A speck of radium on a needle was positioned about one millimeter above the screen. Its distance from the screen could be adjusted with a thumbscrew. With the source far from the screen, individual scintillations could be seen by looking at the screen through the lens. If the radium was brought close to the screen, the screen became a turbulent, luminous sea. Crookes named this invention a "spinthariscope," from the Greek word *spintharis*, "spark."

The spinthariscope became a toy of the well-to-do. It was a great hit at parties, and everyone had to have one. Later, Ernest Rutherford and his assistants used a spinthariscope-like device to measure the charge on an alpha particle and to show that most of the mass of an atom is concentrated in a central nucleus. Rutherford fired alpha particles at a thin gold foil. Carefully counting scintillations showed how many alpha particles were scattered at various angles. These data were also used to estimate the size of the nucleus.

ity. He showed that the gas emitted by uranium during its decay was helium 4. He also found that elements more radioactive than uranium could be extracted from uranium. Over time, the residual uranium regained its radioactivity, while the extracted elements became less radioactive. These experiments laid the groundwork for the discovery of decay chains. For example, it was later learned that uranium decays to thorium, which decays to radium, which decays to radon, and so forth, on down to lead. Consistent with Crookes's findings, radium and radon are more radioactive than uranium and therefore decay more quickly.

Crookes's brother Philip died in 1869, a time when Spiritualism flourished in England. Spiritualism teaches that the spirits of those who have died can be contacted by individuals called mediums—intermediaries between the living and the dead. Crookes wanted to believe, but he exposed some mediums as frauds. He eventually was persuaded that there were some authentic mediums: Daniel Dunglass Home and Eva Fay from America, and a fifteen-year-old English girl, Florence Cook, who supposedly produced a spirit named Katie King. Early in his studies of the radiometer, Crookes found the motion of the vanes so remarkable that he wondered if some new force were involved, perhaps a psychic force. If so, the radiometer might be used to detect true psychic power. (This test was unsuccessful.) His investigation of Spiritualism continued from 1870 to 1874. After his active investigations ceased, he continued to maintain that some mediums had real power to contact departed spirits. He died in London in 1919.

IMPACT

Crookes was one of the preeminent scientists of his day, and therefore one of the most influential. His discovery of thallium established his reputation, and on that basis he was elected a fellow of the Royal Society in 1863. The Royal Society of London was the most prestigious scientific society in England, and he later served as its president. At various times, he was also the president of the Chemical Society, the Institution of Electrical Engineers, the British Association, and the Society of Chemical Industry. He was a member of twenty other scientific societies. He was knighted in 1897, and in 1910 he received the Order of Merit. Altogether, he was awarded fourteen medals and citations.

Crookes developed a vacuum system that could reduce pressure to one-millionth of an atmosphere. This method would later be used by Thomas Alva Edison in the production of electric light bulbs. Crookes had speculated that the particles of cathode rays were negative gas ions, but in 1897 Joseph John Thomson identified these particles as electrons—the first subatomic particles discovered. It is likely that had he been looking for them, Crookes would have discovered X rays. Occasionally, when he operated a Crookes tube, he had lightproof film packets nearby. After using the film packets, he developed the film and found it foggy. Although he complained to his film supplier, it is likely that the film was fogged by X rays from his Crookes tube.

During his last years, Crookes remained active in various science organizations and served as a government consultant. For example, at government request he designed goggles that would protect workers from harmful rays (probably ultraviolet) emitted by molten glass. He wrote numerous scientific articles and books on chemical analysis, dyeing, diamonds, and manufacturing sugar from sugar beets.

—*Charles W. Rogers*

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rays, his conclusion that they are particles, and his proof that they travel much slower than light. The rest of the chapter provides context.

See also: Robert Wilhelm Bunsen; Sir James Dewar; Thomas Alva Edison; Michael Faraday; Joseph von Fraunhofer; Wilhelm Conrad Röntgen.

CARESSE CROSBY

American garment maker

Crosby designed, developed, patented, produced, and marketed a modern brassiere in 1914 upon which American designers and manufacturers modeled the expansion of the brassiere industry in the United States.

Born: April 20, 1892; New York, New York
Died: January 24, 1970; Rome, Italy
Also known as: Mary Phelps Jacob (birth name); Polly Jacob Peabody
Primary field: Household products
Primary invention: Backless brassiere

EARLY LIFE

Called Polly by her family at her insistence, Caresse Crosby was born Mary Phelps Jacob, the oldest of three children of Mary Phelps and William Jacob, an upper-class family with impeccable pedigrees on maternal and paternal sides. Her brothers were Len and Buddy. She grew up in an elegant brownstone on West Fifty-ninth Street in New York City. Her family was aristocratic, employing servants and governesses who attended to the needs of each of the children. In 1897, the family moved to New Rochelle, New York. Polly played dress up in her mother's clothes and fantasized in her treehouse.

Crosby received no formal schooling, though soon she was sent to live with her cousin Ben Barnum, who enjoyed the attention of a private tutor. She learned to read under the tutelage of her British teacher, Blanche Kimber. She read, wrote, drew, produced a gazette with her cousin, danced, rode horses, and visited nearby families. Charles Dana Gibson, originator of the "Gibson Girl" icon, photographed her several times. In the meantime, her family returned to Manhattan, where she eventually rejoined them in 1903 after Ben was sent off to boarding school. Crosby attended Miss Chapin's School from 1903 to 1906. By the time she was fourteen years old, she met her first husband, Richard Rogers Peabody, who later proposed to her, hoping that she might wait for him until his Harvard graduation some years ahead. At the age of fifteen, Crosby attended boarding school at Rosemary Hall in Greenwich, Connecticut, a sister school to Choate, while her father moved to Texas to cure his asthma. He died over the Christmas holiday.

LIFE'S WORK

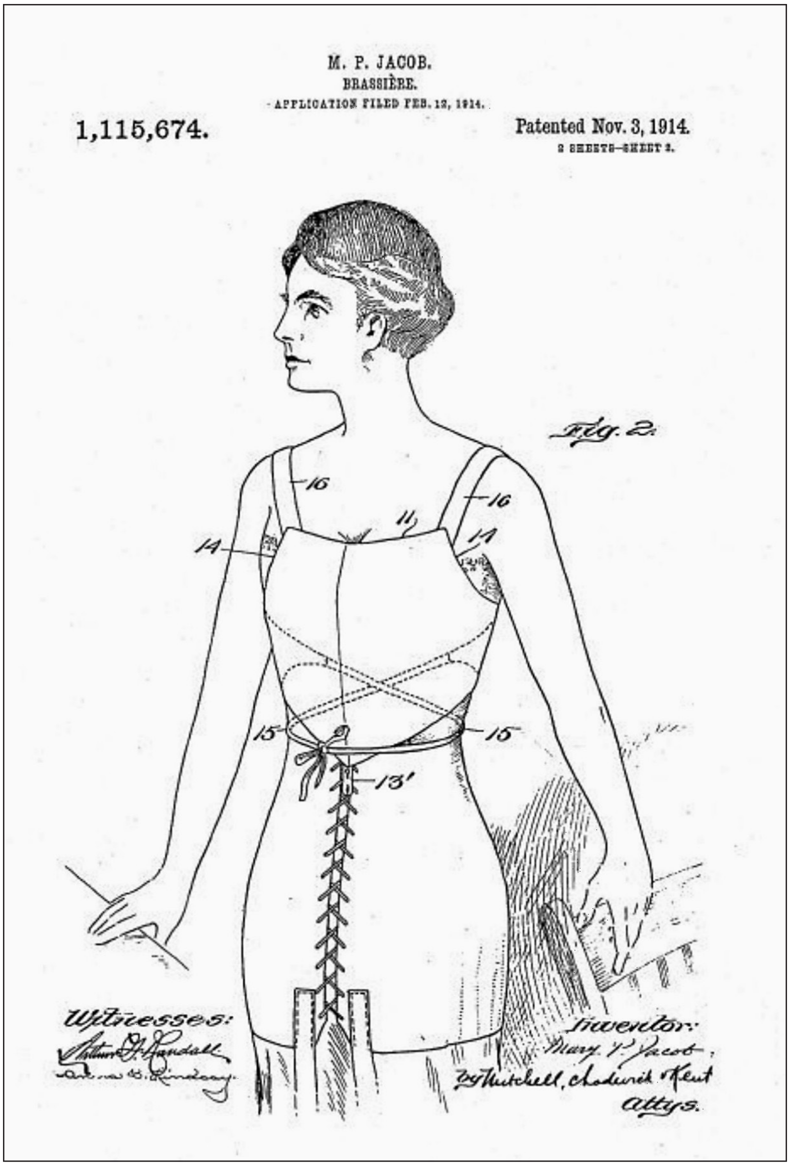
In the spring of 1914, Crosby experienced the distinction of having been the only American debutante to be presented to King George V at court in Windsor, England. After returning to the United States, she settled again with the Barnums on East Forty-fifth Street in an experimental communal home called the Home Club. Crosby and the other young women in residence each wore a whalebone corset and corset cover underneath their clothing, which was de rigueur for the time to provide appropriate foundation and support for fashionable styles as well as to conform to standards of the female form. That November, her great discomfort with, and hatred of, the binding corset cover compelled her to discard it and design a backless brassiere, which would become the first modern bra.

Crosby intended for women to wear her corselette with backless and sheer gowns, as well as those revealing a great deal of décolleté. Her bra was secured over the bust by tapes that crossed at the waist and tied there at the front—quite an improvement from her hastily constructed prototype. The bra was a "one-size-fits-all" undergarment that was adjusted by changing the length of the ties at the end of each tape until the wearer found the fit acceptable. Crosby chose elastic for its straps to prevent the kind of binding she found uncomfortable in the original corset cover. She found her invention appropriate to wear while playing sports, especially tennis.

Upon her return to the United States after a trip to Europe that fall, Crosby was granted a patent for her backless brassiere on November 3, 1914, under the name M. P. Jacob. She fully credited herself for invention of the brassiere and attributed her creativity to an ancestor on her mother's side, Robert Fulton, who made improvements in steam navigation and ultimately invented the first commercially viable steamboat.

Crosby married Peabody in 1915 and had two children with him. Over the next five years, she was consumed with postpartum depression, isolation, and familial obligations. When her husband enlisted in World War I, she joined the American Red Cross and worked as a switchboard operator. Crosby wearied of dealing with her husband's posttraumatic stress disorder that led to his alcoholism. His inability to settle into domestic life resulted in his eventual commitment to a sanitarium. In 1920, Crosby filed legal paperwork with the Commonwealth of Massachusetts indicating that she was a married woman conducting business, the Fashion Form Brassiere Company, separately from her husband.

By 1921, Crosby had broached the subject of separation or divorce from her husband. She sought to earn money to support herself and her children by selling her brassiere. Her company's small factory was based on Washington Street in Boston. Besides providing space for the two employees who cut fabric and sewed the pieces together, thus fashioning brassieres that were successfully marketed to several department stores, she used the business as a setting for assignations with her lover Harry Crosby. Sales of her product were dismal, however. She shut down the factory and left Boston for New York City.



Caresse Crosby's backless brassiere, from the original patent application of 1914. (U.S. Patent and Trademark Office)

After selling her patent to Warner Brothers Corset Company and moving to New York, Crosby tried her hand at acting, taking the stage name Valerie Marno. Her daughter Polleen's illness drew Crosby home before she realized any great success in that profession. With her divorce from Peabody final in February, 1922, she spent much of the rest of the year in Paris with Harry Crosby. On September 9, 1922, the couple married. They brought her children with them in their return to Paris, where she began a new life and career as a wealthy expatriate traveling in fashionable and intellectual Parisian circles. In 1927, the couple founded Black Sun Press. The Crosbys published the writings of D. H. Lawrence, James Joyce, Kay Boyle, Ernest Hemingway, Hart Crane, T. S. Eliot, and Ezra Pound, along with other writers. Harry Crosby killed himself in 1929, and though Caresse remained in Paris until 1936, she eventually returned to the United Sates, where she continued working with artists and writers as well as channeling her efforts into politics. In 1949, she founded Women of the World Against War, which evolved into Women Against War and Citizens of the World in 1950.

THE BACKLESS BRASSIERE

Caresse Crosby designed the first modern bra using two pocket handkerchiefs, ribbons, a needle, and thread. She pinned the handkerchiefs together on the bias as a friend sewed the ribbons to the points below Crosby's breastbone. Crosby then knotted the handkerchiefs' ends around her waist while her friend pulled the ribbons taut and attached them to the knots at Crosby's waist. Besides providing comfortable support, Crosby's brassiere flattened full bosoms as much as possible, which conformed to the style of the time—the virginal appearance. The simplicity of her bra was appealing because it lacked buttons, bones, and hooks that pressed painfully into women's flesh, thus marking and causing the skin to redden and swell. Other young women were impressed by her ingenuity and asked Crosby to construct similar garments for them. Wearing comfortable clothing and undergarments was important to this group of young women, as their main social outlet was attending balls. Some sources credit Crosby's invention to the year 1913 (instead of 1914), but this may be due to her faulty sense of chronology.

The popularity of Crosby's invention surpassed her immediate social circle. After Crosby received a letter from a stranger asking to buy her brassiere for a dollar, she turned her eye toward the possibilities of entrepreneurship and took steps to protect her idea. A Harvard law clerk, Mr. Jones, employed by Mitchell Chadwick & Kent, assisted Crosby's patent application for a corselette, essentially a corset cover that served as an undergarment but which lacked whalebone support and construction. Jones's excitement about the product was evidenced by a series of schematic brassiere drawings that he produced for her the next day. Originally, Jones asked Crosby for $50 to file the patent, but she could not afford the fee. They agreed that she would pay $5 up front and an additional sum once the patent was obtained. Jones filed the application on February 12, 1914.

Crosby borrowed $100 from a friend and rented a room in the sweatshop district of Boston. She rented two sewing machines and employed two Italian girls to sew brassieres according to her design. They produced several hundred backless brassieres, which Crosby took great care in packaging and marketing. She made personal calls to three department stores that each bought one dozen bras. Unfortunately, the bras did not sell. Crosby failed to pursue additional marketing opportunities because she was occupied by her wedding plans. She sold her patent years later for $1,500, a large sum at that time, through Johnny Field, a contact she had at the Warner Brothers Corset Company in Bridgeport, Connecticut.

IMPACT

Crosby's desire to dance and socialize in comfort resulted in a product that allowed women to perform their daily activities in comfort without negatively affecting their well-being. The backless brassiere's light weight and unobtrusiveness offered unrestricted movement and air circulation during stifling temperatures. While her bra was not the first of its kind, its design was popular, comfortable, and easy to manufacture. When the United States entered World War I in 1917, the U.S. government requested that women stop buying corsets in order to conserve metal for military purposes. Unfortunately, she sold her patent to Warner Brothers Corset Company, which profited greatly from her invention, making more than $15 million over the next thirty years.

Upon her death in 1970, her extensive literary endeavors were eclipsed by her simple invention at the age of twenty-two. As the inventor of the first modern bra, Crosby created a foundation from which other designers and inventors could build.

—*Rebecca Tolley-Stokes*

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See also: Levi Strauss.

CTESIBIUS OF ALEXANDRIA

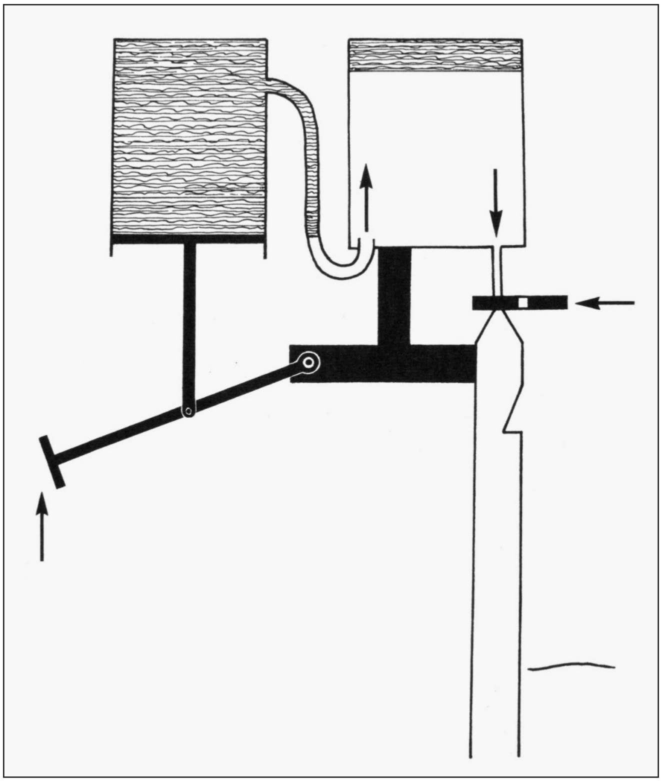
Greek engineer

Ctesibius is generally considered the "father of pneumatics" because of his experiments, devices, and writings on the elasticity of air. He is best known for inventing the force pump and water organ and for refining the water clock.

Born: c. 290 B.C.E.; Alexandria, Egypt
Died: Probably after 250 B.C.E.; Alexandria, Egypt
Also known as: Ktesibios
Primary fields: Civil engineering; mathematics; physics
Primary inventions: Force pump; water organ; precise water clock

EARLY LIFE

Ctesibius (teh-SIH-bee-uhs) was born in Alexandria, Egypt, around 290 B.C.E. Little is known about his early life. He was the son of a barber and may himself have been a barber before pursuing his career as an inventor. He demonstrated his ingenuity and cleverness at an early age through the invention of practical devices for his father's barbershop. In one such device, Ctesibius designed a retractable mirror operated by a series of pulleys set into wooden channels. As the mirror was raised or lowered, the pulleys would move the air in the channels, causing an audible sound. The young inventor's observations of how air was affected by the counterweights in the channels led Ctesibius to pursue further research into hydraulics and hydraulic machines.



A diagram of the mechanism of Ctesibius's water organ. (The Granger Collection, New York)

LIFE'S WORK

How and when Ctesibius left his trade as a barber and devoted himself to the study of pneumatics and hydraulics is unclear. Regardless, it was at the Mouseion of Alexandria, which included the famed library, that Ctesibius was most likely able to conduct his experiments on air and water and to write his treatises, which survive only in fragments quoted by other ancient authors. It was probably during his tenure at the Mouseion that Ctesibius made his lasting contributions to physics and engineering, but with the initial intention of devising practical applications for his pneumatic devices.

By far Ctesibius's most enduring achievement was the force pump. The device consisted of an inverted-T pipe with cylinders attached at both arms of the T. Each cylinder contained a plunger and a valve, and the T-joint contained two additional valves. As pressure was applied to one plunger, water was forced into the joint of the T-pipe, and pressure released from the second plunger, raising it up. This action created a corresponding reaction in the valves: The intake valve in the relaxed cylinder opened to allow more water to enter; its corresponding valve in the T-joint closed, preventing water from backing up; and simultaneously, the intake valve in the stressed cylinder closed, and its corresponding valve in the T-joint opened, forcing the water into the joint and out a single discharge pipe.

Surviving examples of force pumps and descriptions in literary sources provide ample evidence for reconstructing Ctesibius's device. These sources further suggest that Ctesibius is to be credited with the invention of the cylinder, plunger, and valve. It is a great irony that Ctesibius's force pump, which the Romans would later employ effectively in fire extinguishers, offered no remedy for saving the Library of Alexandria from consummation.

Many of Ctesibius's treatises and inventions were refinements of his work on the force pump. He applied his knowledge of the elasticity of air to devising a water organ. He also discussed his ideas on the science of air in his book *On Pneumatics*, which survives only in fragments from various ancient sources. One of the best sources for excerpts of Ctesibius's treaty on pneumatics is Hero (or Heron) of Alexandria, who copied extensively from his mentor and may have been his pupil at the Mouseion of Alexandria. Other works by Ctesibius have been cited by ancient authors, but those original texts remain mostly unknown. Included among these are an account of Ctesibius's life work and treatises on mechanics and military devices.

The water clock of Ctesibius was not strictly a new invention but rather a marked improvement of a long-standing device. The simple water clock had a long tradition going back to the second millennium B.C.E. Early Greek water clocks measured a set unit of time without recording intermediate periods, much like an egg timer. Ctesibius was the first person to substantially improve the simple design. His innovations were threefold. First, he added a supply tank that allowed a constant inflow of water to the reservoir tank set at a lower position. Second, in the reservoir tank, he placed a float with a grooved vertical bar (a rack) on which was mounted a figure with a pointing device. This was used in conjunction with a vertical scale aligned with the pointer. Third, he regulated the rate at which the pointer marked hours by means of a separate wheel with teeth (a pinion). As the float moved up with the level of the water, the teeth of the rack engaged those of the pinion, controlling and standardizing the motion of the pointer. A deficiency in his design—and one that Ctesibius himself recognized—was the water clock's inability to compensate for seasonal hours. He tried to remedy this by varying the time scale with curved lines along a cylinder. The cylinder would then be rotated to the appropriate scale according to the current date. Ctesibius's original device does not survive, but the Roman architect Vitruvius describes it in his treatise *De architectura* (c. 20 B.C.E.; *On Architecture*, 1711). This represents the first reference to the use of gear wheels, especially a rack-and-pinion drive.

Ctesibius was able to apply his new knowledge of pneumatics and hydraulics toward other practical and sometimes whimsical inventions. He equally applied his pneumatic technology to improve devices for war (catapults that employed torsion springs and a version of the siege tower), service (hydraulic lift), entertainment (mechanical birds that sang using variations of air pressure, and automata for entertainment at parties), and belief (automata for providing magical signs from the gods for the masses at temple rituals).

THE HYDRAULIS

The hydraulis, or water organ, was the first keyboard instrument and was the natural outgrowth of Ctesibius's force pump. It represented a mechanization of a simple musical instrument, the panpipes, which was popular among ancient Greek musicians. More than a mechanized version of a simple wind instrument, however, the hydraulis opened the door to new types of musical instruments, genres of sound, and modes of performance.

The hydraulis displays a developed understanding of the technology of the force pump and pneumatics. While its practical uses were few, the hydraulis exemplified Ctesibius's proclivity, seen at an early age, to transform theoretical ideas and experimental mechanics into functional devices. The instrument consisted of a pair of levers that operated two cylinders. The cylinders forced air into an inverted funnel set in a chamber partially filled with water. From the top of the funnel (that is, the narrow opening), air was circulated through the pipes of the organ via channels. A series of valves connected to the keyboard regulated which channels were open and for how long. The varying size of the channels and organ pipes further dictated the quality of the sound generated. In essence, the force applied to the levers was transferred through the water in the inverted funnel and to the air inside the channels. The added energy increased the air pressure, which was released when the keys were played and a sound generated.

Although its initial value as an instrument was not highly appreciated, by the first century C.E. it became a popular instrument of entertainment. Representations of the hydraulis have survived in the form of Roman baked-clay models, in mosaics, and in relief sculpture. Parts of two water organs have been found near Acquincum (modern Budapest, Hungary) and Dion, Greece.

IMPACT

Ctesibius was truly the first to marry the philosophical inquisitiveness of Greek philosophers studying the nature of water and air with more technological applications in order to conceive and to create practical devices.

Numerous devices, both ancient and modern, are essentially permutations of his force pump or water organ. Among the most commonly recognizable of these later inventions are the pipe organ, cuckoo clock, and fire extinguisher. Along with Archimedes, Ctesibius is one of the few inventors to have a device bearing his name, *mechina ctesibica* (force pump).

Ctesibius's writings were no less important. Because no complete text of his treatises survives, the notoriety of Ctesibius must be recognized in the extent to which he was quoted in antiquity. The leading minds of the Greco-Roman world repeatedly mention, paraphrase, or quote his work on pneumatics.

The patrons of the Mouseion of Alexandria, and thus Ctesibius, were the Ptolemaic kings of Egypt. Their patronage prompted mechanical developments of practical, whimsical, and, especially, strategic devices and technologies. From what remains of his writings, one may infer that Ctesibius worked to advance practical mechanics in order to improve weapons and artillery, a strategy he thought was better for preserving peace than simply philosophy or sophistry. Ctesibius was a doer, not just a thinker. Even today, individuals who make notable contributions to the theoretical and practical application of systems, control, and automation are awarded the Ktesibios Award by the Mediterranean Control Association.

—Víctor M. Martínez

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See also: Archimedes.

NICOLAS-JOSEPH CUGNOT

French engineer

Cugnot invented a vehicle powered by steam called the fardier à vapeur, *or steam dray. This three-wheeled carriage was said to be able to pull up to four tons at a speed of four kilometers per hour.*

Born: February 26, 1725; Void, France
Died: October 2, 1804; Paris, France
Primary fields: Automotive technology; military technology and weaponry
Primary invention: Steam dray (*fardier à vapeur*)

EARLY LIFE

Nicolas-Joseph Cugnot (koon-yoh) was born on February 26, 1725, in Void, a small village in eastern France. The child of farmers, Cugnot attended school in Void and later in nearby Toul, where he showed great talent in mathematics and physics. This skill led him to enroll, when he was sixteen, in L'Ecole Royale du Génie de Mézières, a school of military engineering located about one hundred miles west of Toul.

After graduating, Cugnot entered the French army as an officer in the artillery corps. Sent to Vienna when the duke of Lorraine was crowned Emperor Francis I of Austria, Cugnot benefited greatly from his introduction to the German-speaking world. While on post, Cugnot read German engineer Jakob Leupold's *Theatrum Machinarum* (1724), which described all the steam machines invented up to that time. Introduced to the mechanical structure of steam engines, Cugnot was intrigued by the potential of such a novel source of power. He was later sent to Brussels, where he was assigned to fortification design. Wrestling with the mechanical problems involved in constructing artillery defenses and maximizing the effective use of cannon through flexible emplacement, Cugnot began to consider the possibility of using steam power to quickly move immensely heavy weapons to new locations.

LIFE'S WORK

In 1763, at the age of thirty-eight, Cugnot was discharged from the army. Awarded a 600-franc pension in recognition of his invention of a new cavalry musket, he was secure from penury but certainly not wealthy. Taking advantage of his financial security, Cugnot immediately moved to Paris, where in 1766 he published a book titled *Éléments de l'art militaire ancien et moderne*. In 1767, he began work on the design of a military vehicle powered by a steam machine. Needing more funds to build his invention than his pension could supply, he contacted General Gribeauval, his superior officer in Vienna and now inspector general of the French army in Paris. Impressed with Cugnot's design and plans, Gribeauval ordered him to build a small prototype of his machine. Gribeauval successfully guided Cugnot's project through the mazes of royal bureaucracy, gaining the support of the Marquis de Monteynard, the minister of war, and the financial support of King Louis XV.

Cugnot's first working prototype, which took almost

THE STEAM DRAY

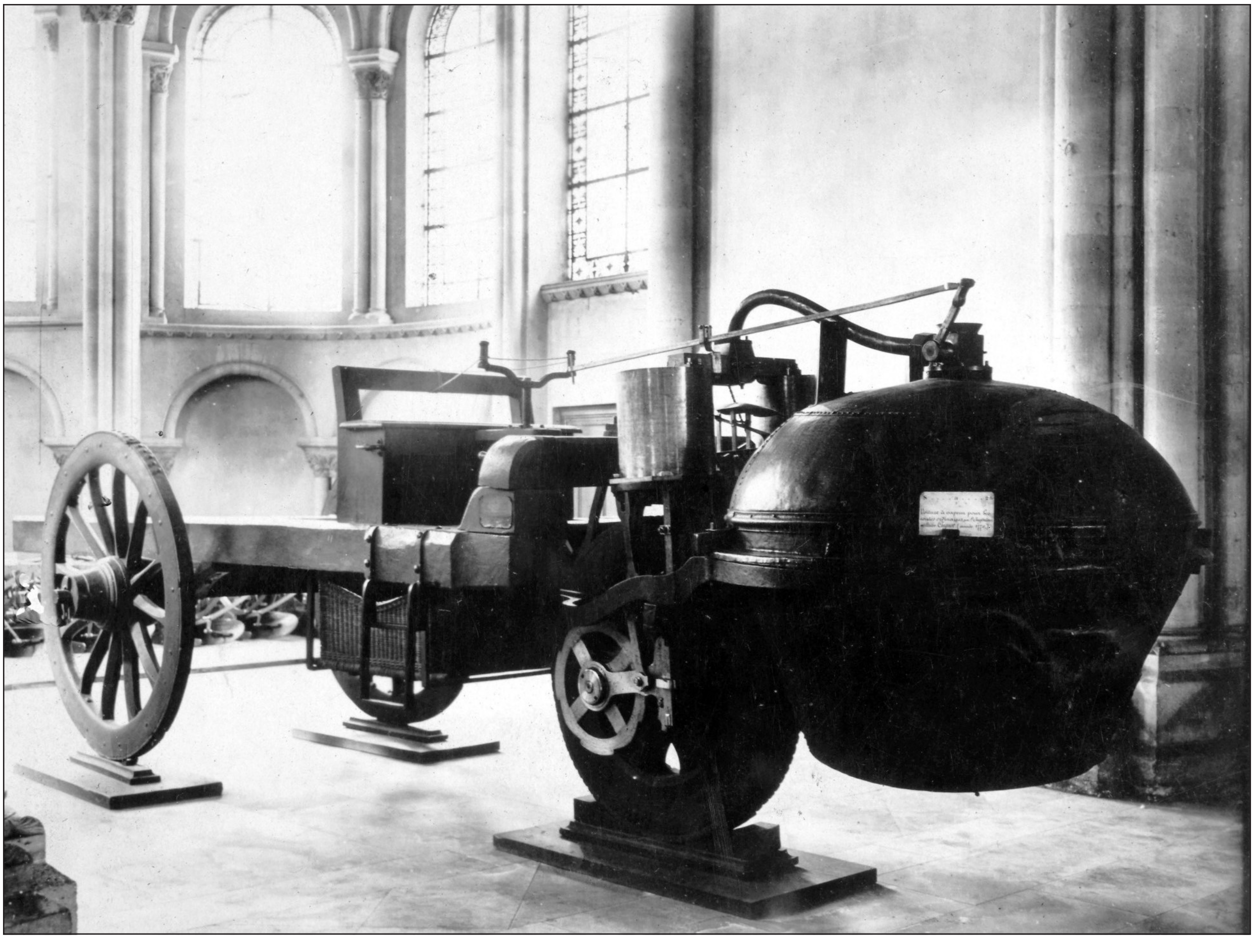
The improved version of the steam dray that Nicolas-Joseph Cugnot presented officially to King Louis XV and his court on April 22, 1770, was able to move at a speed of about 4 kilometers per hour (2.5 miles per hour), although this was less than the speed requested by General Gribeauval. The *fardier à vapeur* had three heavy wooden wheels reinforced with metal: one in the front, which was used for steering, and two in the back to support the load. The two-cylinder steam engine and copper boiler were positioned at the front of the machine. Behind the narrow driver's seat was a platform for transporting equipment. This platform, made of wood reinforced by metal, supported the weight of the load. The steam engine was held on the platform by two arms made of iron. When the platform was not loaded, this vehicle was unstable because of the uneven distribution of the weight. The instability of Cugnot's *fardier* made it difficult to maneuver.

When the *fardier* was demonstrated to the king, the smoking behemoth performed with some success. Still, the problems of maintaining steam had not been satisfactorily resolved. The *fardier* still needed to stop every ten to twelve minutes to build up enough steam pressure to continue to drive a little further. Worse, it lacked any efficient way to replenish the boiler's supply of water, requiring a difficult and time-consuming process for resupply. Fuel could be loaded in the boiler only when the *fardier* was stopped. The boiler did not close perfectly, and steam escaped, making it difficult to maintain a high enough pressure inside the boiler. Safety was another concern, as the machine lacked both a safety valve and a pressure gauge. Nevertheless, Cugnot's efforts were impressive for his time.

three years to develop, made its debut before Gribeauval and other high-ranking French officers in Paris on October 23, 1769. Called a *fardier à vapeur* by its inventor (and a "locomotive" by the English press that reported it), the machine was not a complete success. Though it moved a short distance under its own power, it needed to stop frequently to allow more steam pressure to build up inside the boiler. It would take between twelve and fifteen minutes for the pressure to reach the desired level and allow the prototype to move again. Nevertheless, the concept proved to be workable, so the king and the army asked Cugnot to build a full-size *fardier* capable of carrying a load of about four tons.

In January, 1770, Gribeauval sent an order to the Arsenal in Strasbourg in eastern France to immediately build two 14-inch pumps and pistons in accordance with Cugnot's plans. These important parts were to be delivered to the Arsenal in Paris, where in the following months Cugnot continued his second *fardier* development. The construction was completed in early April, 1770. On April 22, 1770, the *fardier*, now called a "steam dray" in English, was presented officially to King Louis XV and his court.

Cugnot was awarded a large sum of money to continue development, building a second model powered by a different and improved two-cylinder steam engine. By mid-November, 1770, the new machine was ready for trial and performed admirably, pulling a 2.5-ton payload from the military arsenal in the suburbs of Paris to Vincennes at the respectable rate of 2 kilometers per hour (1.2 miles per hour). In fact, during a later trial, the machine malfunctioned, hit a wall, and was damaged (producing the first automobile accident in recorded history). Even with its limitations, however, the *fardier* showed considerable promise. The development of more reliable and efficient steam engines would resolve many of its



Nicolas-Joseph Cugnot's 1770 three-wheeled steam carriage. (The Granger Collection, New York) most pressing problems. Cugnot's *fardier* had to be repaired after its accident and was ready for a new trial on July 2, 1771. This new attempt took place either in a park in Meudon or on the road between Paris and Vincennes (accounts vary). New trials were scheduled for the later part of the summer of 1771, but Cugnot's supporters, such as the duke of Choiseul, who had been sent into exile, fell from power and were replaced by conservatives who failed to see the potential of steam power, which could be applied to military or civilian usage.

Cugnot's invention was abandoned, his funding stopped, and his steam machine barely avoided destruction twice during the French Revolution. Napoleon Bonaparte was apparently interested in renewing development, but Cugnot's advancing age and Bonaparte's campaign in Egypt were obstacles that could not be overcome. Though Bonaparte granted Cugnot a pension of one thousand francs per year, the project was never completed and Cugnot in his later years complemented his pension by teaching military engineering at the Arsenal in Paris. Although Cugnot had modest means, he lived above the poverty level on Tournon Street in Paris, where he died on October 2, 1804, at the age of seventy-nine.

IMPACT

Cugnot was among the first engineers to recognize the great potential of self-powered vehicles. While the size and weight of steam engines made them impractical for personal use, their application to military transport seemed a realistic goal. Hampered mainly by the technical limitations of steam technology at the time, Cugnot was a pragmatic engineer who persevered in developing his *fardier* into a workable machine. Ultimately, Cugnot's project was ended by superiors who lacked his vision. His mechanical accomplishment stands as the pioneering work that foreshadowed the great revolutions in power and transportation of the nineteenth century. The opinions of French scientists at the end of the eighteenth century regarding Cugnot's steam machine are well described by Marquis de Saint-Auban, who on March 12, 1779, wrote a letter to the members of the Royal Society of Arts and Sciences of Metz stating that Cugnot's steam dray was supposed to replace horse-drawn carriages and that his machine was as ingenious as it was useless. Saint-Auban described its flaws in a disparaging way. Not only was it clear that the military withdrew their support for Cugnot's invention but even French scientists failed to see its relevance in improving transportation.

Cugnot's dream became an everyday reality in the locomotives that ran on the world's railways, the great steam tractors that transformed agriculture, and, as the twentieth century dawned, the steam-powered automobiles that competed (in many ways successfully) with the internal combustion engine. His second *fardier* has survived and is presently on display at the Conservatoire National des Arts et Métiers in Paris.

—*Denyse Lemaire and David Kasserman*

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See also: Carl Benz; Gottlieb Daimler; Rudolf Diesel; John Boyd Dunlop; Henry Ford; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; André and Édouard Michelin; William Murdock; Thomas Newcomen; Ransom Eli Olds; Stanford Ovshinsky; Charles Parsons; Sylvester Roper; Thomas Savery; Ignaz Schwinn; Richard Trevithick; Felix Wankel; James Watt; Alexander Winton.

GLENN H. CURTISS

American manufacturer of airplanes

An important inventor of the era when the internal combustion engine came of age, Curtiss made major breakthroughs in both the aeronautical and automobile industries, helping to usher in the modern world.

Born: May 21, 1878; Hammondsport, New York
Died: July 23, 1930; Buffalo, New York
Also known as: Glenn Hammond Curtiss (full name)
Primary fields: Aeronautics and aerospace technology; automotive technology; military technology and weaponry
Primary inventions: JN-4 (airplane); internal combustion engines

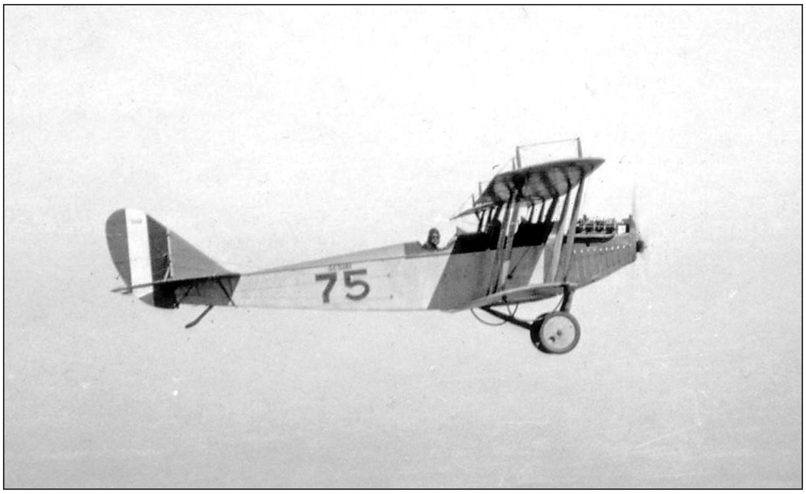
EARLY LIFE

Glenn Hammond Curtiss was a prime example of how brilliance is not necessarily defined by education. Born in rural New York, Curtiss received only a rudimentary education. Less interested in classroom studies than in tinkering with mechanical devices, he left school after only seven years of formal education to find a job that suited his mechanical proclivities. Curtiss found such a job at the Eastman Dry Plate and Film Company, which later became the Eastman Kodak Company, the prominent camera producer. He became a valuable employee, inventing several devices that the company included on its assembly line. Curtiss developed a stencil machine, a lens grinder, and an improved chemical mixer. He also began to tinker with cameras, designing several improved models, although he dropped the project rather than compete with his employer.

Bicycling was a major craze in the late nineteenth century, and Curtiss looked for ways to profit from the fad. He started as a bicycle messenger for a telegraph company, raced bicycles of his own design in local races, and opened his own bicycle shop in his hometown. When the first internal combustion engines appeared in the 1890's, Curtiss was one of the first to see an application for them. He began to attach engines to his bicycles, becoming one of the first motorcycle manufacturers in the United States. The internal combustion engines were crude and unreliable, however, so Curtiss started designing his own, with remarkable results. In 1903, he set the world speed record for a motorcycle, averaging an amazing 64 miles per hour. Only four years later, he more than doubled that speed in setting a new record, 136 miles per hour. The engine for the second test produced forty horsepower, one of the most powerful internal combustion engines of its day.

LIFE'S WORK

Curtiss's life and career changed in 1906, when he became interested in airplanes. Wilbur and Orville Wright were very interested in Curtiss's engines because they were light, powerful, and reliable. Curtiss began to investigate the potential of airplanes, ultimately accepting an invitation from Alexander Graham Bell, the inventor of the telephone, to join an organization he was creating. The Aerial Experiment Association (AEA) brought together a number of American and Canadian inventors to develop aircraft technology in competition with the Wright brothers. While the Wrights worked in private, the AEA operated in public with an official government observer present to document its achievements. This would cause major problems later. The AEA claimed many "official" firsts in the field of aeronautics by demonstrating them in public, but most of its "firsts" had already been accomplished by the Wright brothers, who began to challenge the validity of the AEA's accomplishments.



A JN-4 (Jenny) on a training flight in 1918. (U.S. Army Signal Corps/George Johnson, Aviation Section)

The clash between the Wrights and Curtiss and the AEA started in Europe in 1909. Curtiss flew an aircraft designed by himself and the AEA in the Grande Semaine d'Aviation, the first flying meet ever held, at Rheims, France. The Wright brothers sued Curtiss and the AEA for violating their aircraft patents, particularly the patent on the aileron, a flexible panel on the wing that helps to maneuver the airplane. Curtiss ignored the lawsuit and won the race, earning as a reward a trophy and the right to become the second licensed pilot in Europe (the French aviation pioneer Louis Blériot was the first). The fame Curtiss earned in this race also earned him the honor of receiving the very first pilot's license in the United States, even ahead of the Wright brothers. This first aircraft race was hardly a speedy one. Curtiss averaged 47 miles per hour, much slower than his motorcycles. Nevertheless, Curtiss saw the future of aviation and decided to abandon his motorcycle venture to concentrate on aviation.

Back in the United States, Curtiss continued to win airplane races, and his aircraft designs (the AEA disbanded in 1909) began to attract the attention of the U.S. military, which was intrigued at the potential of the new flying machines. The Wright brothers were pitching their machines to the U.S. Army, so Curtiss concentrated on sales to the U.S. Navy. He moved to San Diego, California, location of one of the Navy's biggest bases, and began to work with the Navy to produce an aircraft to the Navy's particular needs and specifications. Curtiss's fourth design, the Model D, went into limited production as a training aircraft, and Curtiss, as one of the few licensed pilots in the world, trained the first naval aviators. In a foreshadowing of the great aircraft carriers in the Navy's future, Eugene Ely flew a modified Model D off the USS *Birmingham* and two months later, in 1911, landed the plane on the armored cruiser USS *Pennsylvania*.

Designing airplanes for the Navy gave Curtiss an advantage in selling airplanes to various customers. Airfields and airports did not exist in the early twentieth century because the airplane was a new device, and this limited the sales of airplanes. Curtiss, on the other hand, sold airplanes to the Navy, which needed to operate on the world's oceans, so Curtiss's planes were equipped with floats that allowed them to land on water. Curtiss's new design in 1911, the A-1 Seaplane, sold well. The U.S., British, Japanese, German, and Russian navies all purchased planes from Curtiss or bought the rights to produce them under license. The aircraft was such an innovative design that Curtiss became the first recipient of the Collier Trophy, an annual award given out since 1911 for the greatest achievement in aviation. The sale of the A-1 provided enough money for Curtiss to open two new companies. The Curtiss Aeroplane Company produced aircraft designs, while the Curtiss Motor Company designed engines for use on aircraft produced by other companies. Curtiss's financial success, however, only led to more legal wrangling with the Wright brothers, who continued to file lawsuits claiming that Curtiss was

THE JN-4 JENNY

The basic JN-4 had a wingspan of 43 feet, 8 inches, and a length of 27 feet, 4 inches. Derived from the earlier, underpowered JN-3, the JN-4 Jenny featured more advanced control surfaces that made it ideal as a training and observations aircraft. Compared to the JN-3, the Jenny had ailerons on both sides of both wings and a bigger rudder. The earlier aircraft experienced handling problems, and the new control surfaces, along with a larger upper wing (total wing area of 352 square feet), improved maneuverability and made the aircraft more forgiving to trainee pilots who made errors while in flight. The forgiving characteristics of the aircraft also endeared it to many new pilots after World War I; the plane was ideal for the casual pilot who did not need a high-performance aircraft.

Like all aircraft of the era, the Jenny had a wooden frame covered with fabric, a light and simple construction that required little advanced skill to repair. The JN-4 had tandem cockpits with full controls in each seat, meaning that either the front or rear pilot could fly the aircraft. This was especially useful when used as a training aircraft, as the backseat instructor could take control of the plane from the front seat student if necessary. The original OX-5 engine was also very simple. Whereas European aircraft designers opted for complex rotary engines, Glenn H. Curtiss's own OX-5 was an inline design not all that different from a standard automobile engine. This meant that an average pilot/mechanic could repair the engine himself. The OX-5 generated 90 horsepower, enough to lift the 2,000-pound aircraft to a maximum altitude of 6,500 feet and a top speed of 75 miles per hour. The engine power was especially useful to the naval models that had to lift the bulky floats attached to the plane as well. Later models of the JN-4 featured upgrades and changes that reflected early experience with the design and changes requested by wartime users. The final version, the JN-4H model, featured a 150-horsepower engine produced by Wright and was the only armed version. It carried machine guns and small practice bombs as an advanced weapons trainer.

violating their patents on aircraft control surfaces. The lawsuits dragged on for years until finally, in 1913, the courts ruled in the Wrights' favor, and Curtiss had to design new aircraft without the Wrights' patented aileron.

The Wrights' success in the lawsuit was short-lived, however. Wilbur died in 1912, and Orville, weary of the constant battles over their patents, sold the Wright Company to a group of investors. Confident that the Wright Company, which was getting out of the aircraft design business to concentrate on aircraft engine productions, would not continue to sue, Wright returned to designing airplanes. Curtiss designed the H-4, a series of very large "flying boats." He sold this design to the U.S. Navy and a modified design to the British navy. When World War I broke out, the U.S. government temporarily merged all of the aircraft companies into the Manufacturers' Aircraft Association (MAA), forcing the aircraft companies to work together. The government also suspended patent protections, forcing members of the MAA to share their technology and design expertise. Curtiss took advantage of the arrangement, and he produced the greatest share of American aircraft during the war. He produced a new training aircraft, the JN-4, called the Jenny, for the U.S. Army and a modified floatplane version, the N-9, for the Navy. Altogether, Curtiss produced more than sixty-eight hundred JN-4 and N-9 aircraft before production ceased in 1922.

World War I was a great benefit to Curtiss's companies, but peacetime was not as lucrative. Curtiss Aeroplane survived thanks to two new areas of production. Curtiss's background in large flying boats paid off when increasingly larger flying boats became the preferred mode of long-distance travel in the 1920's and 1930's. Curtiss's expertise in seaplanes also benefited the company when competing for the Schneider Trophy, a prestigious award granted to the winner of an annual seaplane race. Curtiss won two Schneider Trophies, in 1923 and 1925, cementing his reputation as the country's greatest aircraft manufacturer. The Curtiss Company eventually triumphed over its old adversary when, in 1929, Curtiss acquired the Wright Company, forming a new entity, the Curtiss-Wright Company, that dominated aircraft design and aircraft engine production in the 1930's.

IMPACT

Curtiss and his company produced some of the great mechanical achievements of the twentieth century. His early work on internal combustion engines helped to drive the birth of the motorcycle industry and, by extension, feed America's enthusiasm for speed. By challenging the Wright brothers' lock on aircraft design, he freed American aircraft designers to create the most innovative and advanced aircraft in the world. Curtiss was one of the founders of civilian air travel, and his JN-4 design survived long after the war that prompted its creation. His aircraft introduced a large number of Americans to flying for the first time, and his famous racing planes capitalized on the growing enthusiasm for flight. Besides his World War I and civilian work, his company later produced some of the most important aircraft of World War II, such as the P-40 fighter, SB2C dive bomber, and C-46 transport. His demonstration that aircraft could play a role in naval warfare, however, had the biggest impact among his military projects. His floatplanes and airplanes, whether flying off a cruiser deck or on their own floats, showed that airpower and naval power could function together, foreshadowing the great aircraft carrier battles of World War II and beyond.

—*Steven J. Ramold*

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Roseberry, Cecil R. *Glenn Curtiss: Pioneer of Flight*. Syracuse, N.Y.: Syracuse University Press, 1991. This volume is a basic history of Curtiss's aviation achievements, with a secondary discussion of his legal fights with the Wright brothers. While not the most stirring biography of Curtiss, this book does provide a clear, straightforward account of Curtiss's life and accomplishments.

Shulman, Seth. *Unlocking the Sky: Glenn Hammond Curtiss and the Race to Invent the Airplane*. New York: HarperCollins, 2002. The author vividly describes the legal wrangling between the Wright brothers, who laid claim to all technology related to powered flight, and Curtiss, who represented all of the other aircraft pioneers who felt the Wrights were claiming innovations developed by others. A very readable account, the book ends with Curtiss's eventual triumph over the Wrights when he acquired their aircraft company.

See also: George Cayley; Edwin Albert Link; Nikolaus August Otto; Sylvester Roper; Elmer Ambrose Sperry; Wilbur and Orville Wright.

LOUIS JACQUES DAGUERRE

French physicist

Improving on the discoveries of Nicéphore Niépce and others, Daguerre perfected a photographic process that made possible the first permanent images produced by cameras.

Born: November 18, 1787; Cormeilles, near Paris, France
Died: July 10, 1851; Bry-sur-Marne, near Paris, France
Also known as: Louis-Jacques-Mandé Daguerre (full name)
Primary field: Photography
Primary invention: Daguerreotype

EARLY LIFE

Louis-Jacques-Mandé Daguerre (lwee zhahk mahn-day dah-gaihr) was the son of Louis Jacques Daguerre, an employee of the local magistrate's court in Cormeilles, and Anne Antoinette Hauterre. Shortly after the birth of a daughter, Marie Antoinette, in 1791, the family moved to Orléans, where the elder Louis worked as a clerk at the royal estates. Young Louis and his sister received little formal education; however, Louis demonstrated such a remarkable gift for drawing and sketching that he was soon apprenticed to an architect under whom he trained for three years as a draftsman.

Although Daguerre learned valuable rules of perspective and accuracy during his apprenticeship, he was determined to study art in Paris. He enjoyed drawing much more than architectural design, but his father opposed art as a career choice. In a compromise measure, Daguerre was apprenticed to a well-known Parisian stage designer, Ignace Eugéne Marie Degotti, in 1804. Working in Degotti's studio, Daguerre learned quickly and was given a major role designing several important productions.

Daguerre's irrepressible personality made him many friends in the artistic community. He enlivened parties where singing, dancing, and acrobatics were popular, sometimes even making dramatic entrances walking on his hands. He also performed in choreographed scenes in the Paris Opéra and executed tightrope acrobatics with great skill. Throughout his life, Daguerre benefited from an abundance of energy and endurance.

LIFE'S WORK

In 1807, Daguerre became an assistant to Pierre Prévost, a panorama painter, and in 1810 married Louise Georgina Smith, sister of a painter who later became Daguerre's colleague. The popularity of panoramas, immense paintings exhibited in circular buildings, had made Prévost famous. He and another businessman collaborated to build an exhibition in which the display measured more than 100 feet in diameter and featured a painting more than 350 feet in length and 52 feet in height. Daguerre's earlier training as a draftsman contributed to the accuracy of these paintings, which frequently depicted patriotic scenes. He remained in Prévost's employ until 1816, when he returned to stage design under contract to the small but well-established Théâtre de l'Ambigu-Comique. A new genre known as melodrama attracted enthusiastic audiences that Daguerre impressed with extravagant visual illusions. He created stage designs for thirteen shows in the years 1816-1822, utilizing spectacular visual effects and increasing his reputation as an innovator in the theatrical world. It was during these years that he began experimenting with a range of lighting effects using gas lamps.

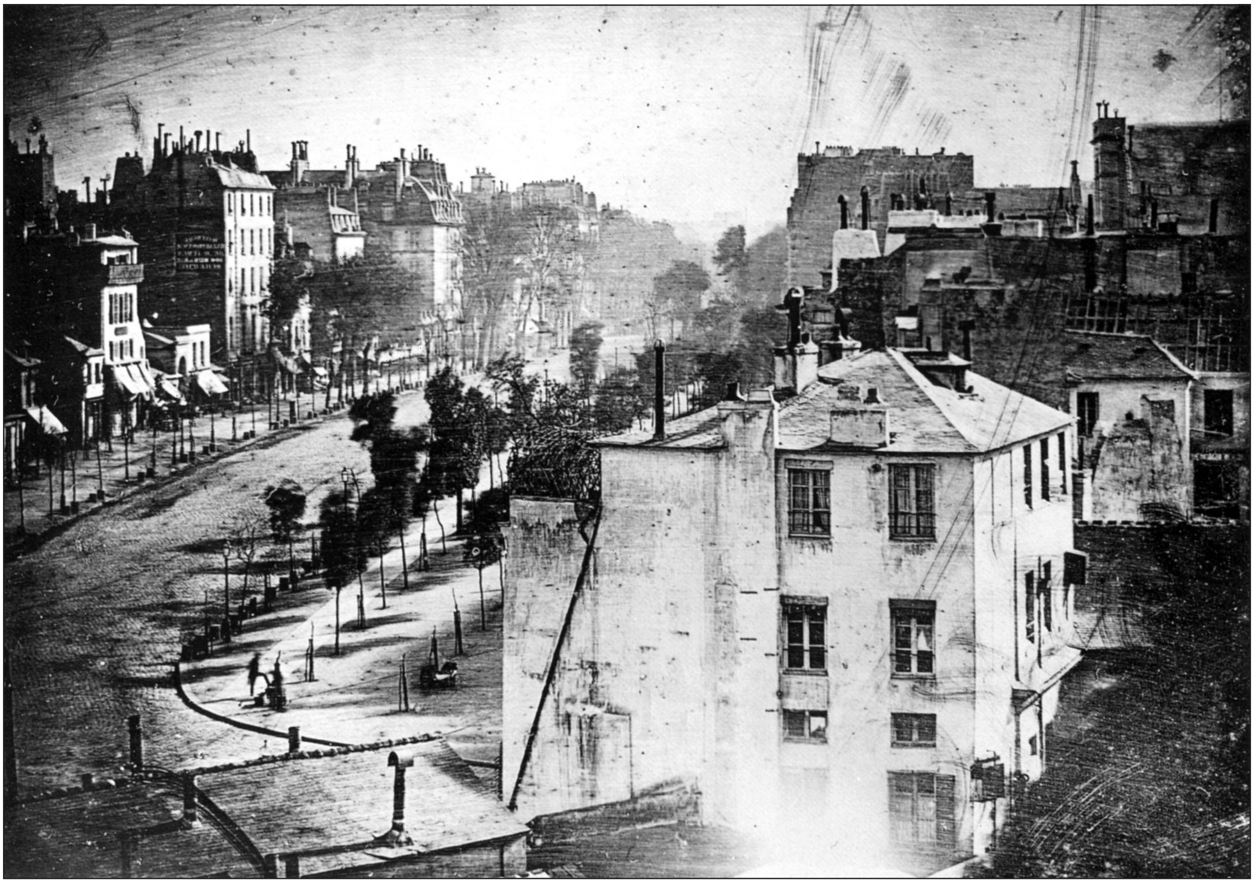
As early as 1822, Daguerre worked to develop a new form of public entertainment, the diorama. In the earlier "diaphanorama" created by Franz Niklaus König, transparent paintings exhibited in darkened rooms were illuminated by specialized lighting and reflection. Daguerre improved the diaphanorama so much that he was able to patent the diorama as a new invention. His earlier panorama displays only portrayed subjects from one perspective during a fixed time, but the diorama treated awestruck viewers to gradations of light that seemed to flow over and sometimes even through paintings. In ten or fifteen minutes, the illusion revealed landscapes or chapel scenes passing from day to night. Natural disasters such as erupting volcanoes and tumbling landslides were also portrayed.

In connection with his work in lighting and design, Daguerre hoped to discover a mechanical means by which natural scenes and perhaps even portraits of people could be preserved. Although Daguerre had used a camera obscura—a device that focused sunlight through a lens to cast an image—in order to improve the realism of his paintings, the images always vanished when the light failed. Other inventors were also interested in developing a way to record images created by sunlight.

As early as 1816, Nicéphore Niépce had begun experimenting with a variety of materials, including paper treated with various light-sensitive chemicals. In 1826, he succeeded in producing an image on a pewter plate coated with bitumen, a process he named "heliography," or sun-drawing. Hearing of Niépce's work, Daguerre contacted the inventor to suggest an alliance, but Niépce hoped to patent his work in England. When this plan failed, he agreed to a partnership with Daguerre, who had been experimenting on his own with lenses and varying chemical treatments to metal plates. As the two men corresponded, Niépce revealed his findings to Daguerre, who struggled to improve upon them.

It was not until after Niépce's death that Daguerre discovered, in 1837, substantially improved methods of recording images. He managed to decrease exposure times from seven or more hours to minutes and to devise a treatment that kept the images from fading when exposed to light. Daguerre announced his success but kept his methods secret, since he believed that the process could easily be copied and would bring him no profit if he simply patented it. He claimed to be the true inventor of the new process and attempted to sell subscriptions, planning to grant Niépce little credit for his research and his heir Isadore Niépce a reduced percentage of any earnings. Although businessmen and members of the art industry were very interested, few were willing to invest, and the project stalled.

In an unusual move, the French government granted the partners Daguerre and Isadore Niépce sizable lifetime annuities in exchange for all rights to the entire photographic procedure. Daguerre received a larger grant than Niépce for revealing the secrets of his diorama design and for his promise to disclose any future enhancements to the photographic process that he might discover. The "daguerreotype" was made public as a gift from the French people to the world, and Daguerre was



"View of the Boulevard du Temple" daguerreotype, Paris, 1838/1839. Although the photograph accurately portrays the street, trees, and buildings, only one person on the busy boulevard was recorded—a man who stood still as his shoes were polished (bottom left corner). Exposure time for a daguerreotype was so long that carriages and pedestrian activity moved too fast to be registered on the light-sensitive copper plate.

THE DAGUERREOTYPE

Photography as a practical process began when Jacques Daguerre discovered a way to fix, or make permanent, the images cast on silver-coated copper plates treated with light-sensitive iodide. The metallic plates were exposed as the light traveled through a camera lens, changing the chemical composition of the plates. These were then treated with a mercury vapor, a process that converted the emergent image from a negative to a detailed, positive picture.

The last step in the process made the images permanent. Once the exposed plates had been rinsed in a hot saltwater solution that dissolved the silver iodide that had not been affected by light, the images were fixed and did not fade when exposed to light. Variations of the developing process continued to be an integral part of film-based photography.

As advantageous as this process appeared, there were important limitations. The lengthy exposure time required for success was the greatest drawback to the earliest daguerreotypes, initially making attractive portraits impossible. Each picture required a repetition of the entire process on new plates, and the equipment was frequently judged too cumbersome for practical fieldwork. Also, the fragile images damaged easily and could be seen only when viewed from an angle, due to the glare produced by the silver coating on the plates.

Freed from patent restraints by the public announcement of Daguerre's process, entrepreneurial camera designers rapidly improved the lenses and other mechanical features of cameras. For example, a mirror prism placed in front of the lens corrected the reversed images produced by the original cameras. Another inventor created a camera that relied on concave mirrors to reflect images rather than passing light through a lens.

New lens combinations, widened apertures, and an improved chemical process further reduced long exposure times. Antoine Claudet discovered that treating the silver-coated copper plates with both iodide and chlorine greatly accelerated their sensitivity to light. Thus, it became possible to take portraits in the shade in only five to twelve seconds and in full sunshine in only one to four seconds.

Photo-etching methods of deriving prints from finished plates enabled printers to duplicate copies of the originals for publications, but this process was difficult and never became practicable. However, daguerreotypes were used to increase accuracy and to reduce the production time involved in creating lithographs and traditional engravings.

By 1847, French photographers had begun to favor a paper-based process developed by William Fox Talbot. An important new process introduced in 1851 by Frederick Scott Archer that utilized glass plates dipped in a solution containing collodion, or nitrocellulose, contributed to a marked decline in daguerreotype production. Nevertheless the striking, silvery images continued to be highly prized in the United States for many years. Recent interest in the daguerreotype has led to a renewed use of the process, primarily for aesthetic reasons.

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appointed an officer of the Legion of Honor for his accomplishment.

Daguerre attempted to refine the daguerreotype process after publishing *Historique et description des procédés du daguerréotype et du diorama* (1839; *An Historical and Descriptive Account of the Various Processes of the Daguerreotype and the Diorama*), but he was unable to compete with a number of improvements that were rapidly devised by others. He left Paris in 1840 to live in the nearby village of Bry-sur-Marne, where he continued to experiment with photographic equipment and painting methods. In addition, he completed projects in design and the graphic arts as well as receiving admiring visitors from around the world. He died unexpectedly in 1851, apparently of heart failure.

IMPACT

The revelation of Daguerre's invention was hailed as a victory of science, one that opened a new world of instant representation. An eager public awaited the 1839 disclosure of the inventor's process, and by the end of the year enterprising individuals made and displayed daguerreotypes in Britain, the United States, and other countries. The daguerreotype galvanized members of the art world and the public as inventors, lens grinders, lithographers, and chemists sought to make full use of the amazing potential offered by the process.

Photographers began recording landmarks, architectural works, and natural objects in regions as diverse as Switzerland, Egypt, and the United States. Daguerreotypes were prized because they recorded realistic images. Publishers often preferred these truthful representations to romanticized paintings that exaggerated space and size for emotional effects. Printmakers, painters, and fledgling photographers joined to produce an enriched visual culture affecting much of the Western world.

Photography grew rapidly in France, attracting many practitioners. A thousand-piece daguerreotype collection was displayed at an 1844 exposition, and in 1847 as many as two thousand cameras were sold in Paris. In the past, only wealthy art patrons and members of the royalty had been able to afford hand-painted portraits, but with the daguerreotype's increasing availability, many more people could enjoy permanent mirrorlike self-images.

Daguerre's collection of daguerreotypes and the records of his experiments burned when his laboratory, situated in his diorama building, went up in flames in 1839. However, his place in history as a successful painter, physicist, and chemist remains. For example, his name was included in a list of seventy-two world-class French scientists engraved on the Eiffel Tower. Also, although some have considered his scientific methods haphazard and his ambitions overriding, Daguerre was largely successful in convincing the public that he was the discoverer of photography. In more recent academic studies, many historians credit Niépce's earliest heliograph as the true original.

—*Margaret A. Koger*

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See also: Léon Foucault; Samuel F. B. Morse; Nicéphore Niépce.

GOTTLIEB DAIMLER

German mechanical engineer

Daimler was a leader in the early automotive industry and a pioneer of the internal combustion engine, the motorcycle, the four-wheel gasoline-driven automobile, and the world-famous Mercedes-Benz car.

Born: March 17, 1834; Schorndorf, Württemberg (now in Germany)
Died: March 6, 1900; Cannstatt, Germany
Also known as: Gottlieb Wilhelm Daimler (full name)

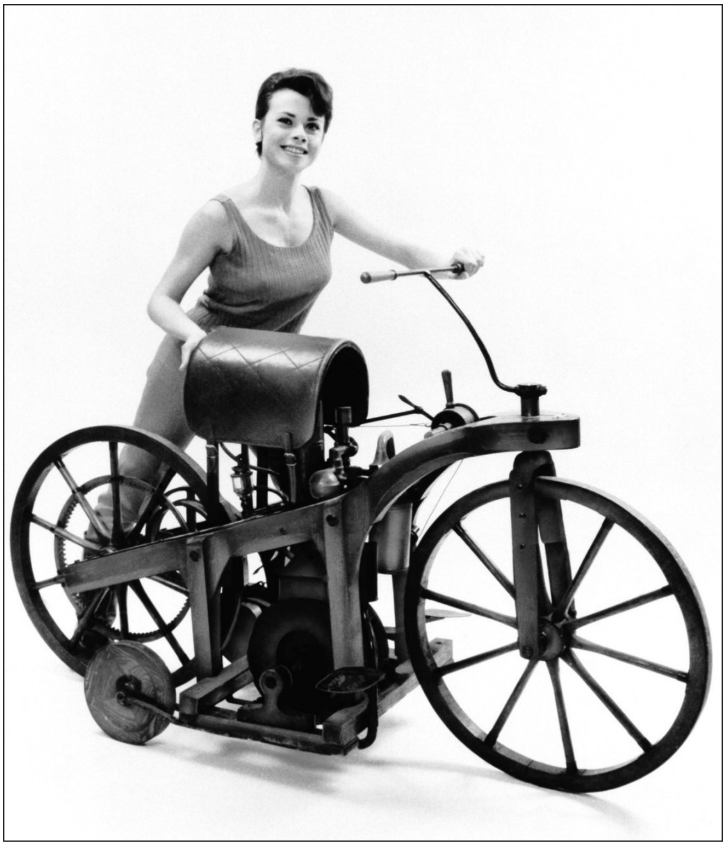
Primary fields: Automotive technology; mechanical engineering
Primary inventions: Daimler's motorcycle; gas engine

EARLY LIFE

Gottlieb Wilhelm Daimler (GOT-leeb VIHL-hehlm DIM-lur) was born on March 17, 1834, in the town of Schorndorf, Württemberg (now in Germany), the son of a baker named Johannes Daümler and his wife, Frederika. At the age of thirteen, he completed his six-year primary studies in Lateinschule, a prestigious grammar school. He showed an aptitude for mathematics, especially geometry, and attended drawing classes on Sundays.

Daimler's first job was as a gunsmith's apprentice. He completed his apprenticeship by making a double-barreled gun. For a period, he worked in France to gain practical experience in mechanical engineering. From 1853 to 1857, he worked at a Strassburg steam engine factory. He then attended the Stuttgart Polytechnic School, taking up mechanical engineering and completing his training in 1859. While most engineering students tried to exploit the power of steam engines, Daimler gained experience by working in various German engineering firms.

Two years later, recognizing the need for a small, low-power engine capable of economical, intermittent operation, Daimler left to tour France and England, where he undertook various technical jobs. In Paris, he saw Étienne Lenoir's new gas engine. He also visited the 1862 London World Fair, where he observed the latest European engineering advances. For a while, he worked as a draftsman in Geislingen, devising systems and tools to mechanize an old factory.



A model poses with the world's first gas-powered motorcycle, built in 1885 by Gottlieb Daimler. (AP/Wide World Photos)

At the end of 1863, he became the workshop inspector at Bruderhaus Maschinen-Fabrik in Reutlingen, where he met Wilhelm Maybach (his future business partner and lifelong friend) in 1865. He married Emma Kurtz on November 9, 1867; they had five children. He left Reutlingen in 1869 and joined a mechanical engineering company in Karlsruhe, where Carl Benz had worked earlier.

Life's Work

In 1872, Daimler became technical director at the world's largest manufacturer of stationary engines of the time, Gasmotorenfabrik Deutz, Nikolaus August Otto's company. Daimler hired fellow inventor Maybach. In 1876, Otto invented the four-stroke engine, known as the Otto cycle, which was to replace the steam engines predominant at that time. It was patented in 1877 but was soon challenged by Carl Benz. In Mannheim, unknown to the other three inventors, Benz was creating a reliable two-stroke gas engine based on the same principle. He completed his engine on New Year's Eve, 1878, and received a patent in 1879. In 1882, serious personal differences between Daimler and Otto resulted in Daimler's being fired. Maybach later resigned.

That year, Daimler and Maybach moved back to Stuttgart and purchased a cottage in Cannstatt, where they started their own engine-building shop in 1885. Among many developments, they patented one of the first successful high-speed internal combustion engines. They used their fuel-injected engines to develop the first gas-engine motorcycle, and they created a carburetor, which mixes gasoline with air for the engine. They also assembled a larger version of their engine, which they called the *Standuhr* (grandfather clock) for its resemblance to an old pendulum clock.

Unknown to Maybach and Daimler, Benz had built the first automobile and was granted a patent for his motorized tricycle in 1886. That year, Daimler and Maybach installed a larger version of the grandfather clock engine into a stagecoach, which became the first four-wheel automobile to reach 16 kilometers per hour (10 miles per hour).

Daimler and Maybach also used their engine in other types of transport and even in Daimler's balloon, usually regarded as the first airship, where it replaced a hand-operated engine designed by Friedrich Hermann Wolfert of Leipzig. With the new engine, Daimler successfully flew over Seelberg on August 10, 1888.

Daimler and Maybach sold their first foreign licenses for engines in 1887, with Maybach representating the company at the Paris World's Fair. Engine sales increased. Daimler bought another property at Seelberg in Cannstatt. In 1889, their efforts led to their first automobile, a two-stroke-engine, four-wheeled vehicle. It was licensed to be built in France; they presented it to the public in Paris in October, 1889. It was also in this year that Daimler's first wife, Emma, died.

In 1890, Daimler and Maybach founded Daimler Motoren-Gesselschaft (DMG) in order to build their high-speed engines. As they struggled financially, two financiers and munition makers, Max von Duttenhofer and William Lorenz, along with the influential banker Kilian von Steiner, agreed to inject some capital, converting the company into a public corporation on November 28, 1890. DMG expanded. The newcomers did not believe in automobile production and ordered the creation of additional building capacity for stationary engines. They also considered merging DMG with Otto's company. Maybach was denied a seat on the board, and he left the company on February 11, 1891.

In 1892, DMG sold its first automobile. Age fifty-eight and ill with heart disease, Daimler traveled to Florence, Italy, on his doctor's orders. There he met Lina Hartmann, a widow twenty-two years his junior and the owner of the hotel where he was staying. They married on July 8, 1893. On his return, Daimler experienced difficulty with other stockholders, and he resigned that year—a move that would prove short-lived.

Maybach, Daimler, and his son Paul had designed a third engine, the *Phoenix*, which DMG manufactured. The *Phoenix* became famous around the world, winning the first car race in history—from Paris to Rouen in 1894. In order to stabilize DMG, British industrialist Frederick Simms negotiated for Daimler's return to DMG, securing the right to license the *Phoenix* engine and use Daimler's name in the engine's branding. In 1895, the year DMG assembled its thousandth engine, Maybach also returned as chief engineer. In 1899, DMG produced the first Mercedes automobile—considered the first modern gasoline-powered car. (The car was named after the

DAIMLER'S MOTORCYCLE

Gottlieb Daimler is credited with inventing the first gas-powered motorcycle. Motorcycle sport is popular in many countries, especially with the young. A motorcycle is a single-track, two-wheeled motor vehicle powered by an engine. It evolved from the "safety" bicycle, which offered advantages in stability, braking, and ease of mounting. Safety bicycles became popular in the late 1880's. They had two wheels of identical size and a chain-driven rear wheel. In 1885, they were simply called bicycles.

That year, Daimler produced his first vehicle, a motorcycle. He attached the gasoline engine to a wooden bicycle, replacing the pedals. His motorcycle was powered by a single-cylinder Otto-cycle engine mounted vertically in the center of the machine. It had one wheel in front, one rear wheel, and a spring-loaded outrigger wheel on each side for added stability. Its chassis mostly consisted of wood; the wheels had wooden spokes and iron rims.

These designs were called "boneshakers" because of the jarring ride they delivered. Daimler's motorcycle may have also included a spray-type carburetor, then under development by himself with his longtime business partner, Wilhelm Maybach, for use in the Daimler automobile that appeared in 1889.

After Dailmer's motorcycle was introduced, other designers followed, including Alex Millet in 1892, Hildebrand & Wolfmüller in 1894, and DeDion-Buton in 1895. By the time Michio Suzuki was designing his first loom, other European companies such as Peugeot, Norton, and Husqvarna were producing motorcycles, as well as Indian and Harley-Davidson in the United States.

Daimler is generally credited as the "father of the motorcycle." However, in 1867 Sylvester Roper in the United States built a primitive motorcycle, a steam-powered bike. Although it did not catch on, it anticipated modern motorbike features, including the twisting-handgrip throttle control. It was powered by a charcoal-fired two-cylinder engine, whose connecting rods directly drove a crank on the rear wheel. This machine predates the invention of the safety bicycle.

What gives credibility to Daimler's claim of having developed the first "true" motorcycle is the fact that his motorcycle was propelled by a gas engine, while Roper's two-cylinder engine was powered by steam. Daimler is rightly considered a pioneer of the motorcycle and automobile industry.

daughter of Emil Jellinek, a businessman who raced Daimler's cars.)

Daimler finally succumbed to the pressures of his forty-year career and heart disease, dying in 1900. In 1907, Maybach resigned permanently from DMG. In 1924, DMG's management signed a long-term agreement with Benz and Cie. Two years later, the two companies merged to become Daimler-Benz AG.

IMPACT

Daimler was a pioneer in automotive history whose efforts immensely impacted the car industry and the creation of the modern automobile. Indeed, Daimler's impact was second only to that of Carl Benz. Independently, Benz and Daimler created vehicles that are now recognized as the ancestors of modern gasoline-powered vehicles. Although they used different approaches—Benz, the spark ignition, and Daimler, the high-speed motor—both paved the way to the future development of the automobile.

Daimler's contributions extend beyond the modern motorcar, however: Before his major breakthrough, he produced the first gas-engine motorcycle and the first four-wheeled, gas-driven car within a year's span. His development of the carburetor launched the age of gasoline-powered automobiles. When he constructed the improved two-stroke, four-cylinder engine in 1889, the stage was set for the modern automobile—which he produced ten years later with the first Mercedes.

Since that time, gas-powered automobiles have had both positive and negative effects: They led to the decline of the railroads and eventually increased greenhouse gas emissions, which many believe are largely responsible for global warming. The automobile also caused both demographic and social upheavals, as more people moved from urban to outlying suburban areas and as teenagers and young adults enhanced their independence from parents and family life. At the same time, today's economy, social flexibility, and productivity are hard to imagine without the automobile.

Another of Daimler's major legacies is his foundation of what became Daimler-Benz AG, which produced the famous Mercedes-Benz automobiles, still considered a gold standard for passenger cars. Many of the innovations Daimler developed are still used in modern vehicles. Thanks to his pioneering inventions and his major role in the automobile revolution, people around the world have enjoyed freedom of movement and increased standards of living.

—*Tel Asiado*

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NILS GUSTAF DALÉN

Swedish physicist and engineer

Dalén invented the sun valve, a device that made it possible for lighthouses to function unattended for a maximum period of one year. He also invented a flashing apparatus, the Dalén mixer, and an automatic mantle changer, as well as Agamassan, all of which helped to improve the lighthouse system.

Born: November 30, 1869; Stenstorp, Sweden
Died: December 9, 1937; Lidingö, Sweden
Primary fields: Mechanical engineering; physics
Primary inventions: Sun valve; AGA lighthouse system

EARLY LIFE

Nils Gustaf Dalén (neels goo-STAHF dah-LAYN) was the third child born to farmers in Stenstorp, Sweden. Since Dalén was not a particularly studious boy, his parents felt that he was the best suited of their children to manage the farm. Because he planned to be a farmer, once Dalén had finished his secondary schooling he enrolled at a school of agriculture with the intention of studying dairy farming. However, Dalén had already started inventing machines while he was living on the family farm. His first invention was a threshing machine, which he powered with an old spinning wheel. His next invention was a mechanism for measuring the butterfat content of milk. This invention brought him to the attention of Gustaf de Laval, founder of the company AB Separator, located in Stockholm. Impressed by Dalén's exceptional talent in mechanics, de Laval recommended that he pursue a technical education. Dalén took de Laval's advice and abandoned his study of dairy farming.

He attended the Chalmers Institute at Gothenburg from 1892 to 1896, graduating with a degree in engineering. Still interested in dairy farming, Dalén invented a pasteurization machine as well as a milking device. He spent a year in Switzerland, where he studied with Professor Aurel Stodola at the Eidgenössisches Polytechnikum. When he returned to Sweden, Dalén did research at Gothenburg and worked for AB de Lavals Angturbin as a turbine designer. He constructed a hot-air turbine with related compressors and air pumps. The turbine project was not successful, however, and Dalén turned his attention toward another area in which de Laval was involved—the industrial use of the gas acetylene. With Henrik von Celsing, whom he had met at Chalmers, he founded the firm Dalén and Celsing.

LIFE'S WORK

The year 1901 was significant for Dalén both personally and professionally. He married Elma Persson and accepted a position as technical chief of the Swedish Carbide and Acetylene Company. In 1904, he began working for the Gas Accumulator Company, and he became the company's chief engineer two years later. In 1909, the company was reorganized and named the Swedish Gas Accumulator Company (Svenska Aktiebolaget Gasaccumulator, or AGA), and Dalén became managing director of the firm.

In 1901, Dalén's company bought the patent rights to the French invention of dissolved acetylene. In 1905, John Höjer, chief engineer for the Board of Pilotage, Lighthouses, and Buoys, brought to the attention of Dalén the large market potential of acetylene, which could be used as fuel in lighthouse beacons, and mentioned the need for economical automatic flashing beacons. Dalén began researching and working on an automatic flashing beacon and produced a flashing apparatus, the AGA flasher, that not only improved lighthouse beacons but also was used in railroad signals. The first railway signal using this flashing apparatus went into operation in 1908. Dalén continued his research on lighthouse beacons and invented the sun valve, or Solventil, in 1907. The device made it possible for lighthouses to function unattended for a maximum period of one year. The sun valve caused a beacon to light at dusk and to extinguish at dawn automatically, thereby conserving fuel. In 1912, he received the Nobel Prize in Physics for this invention.

In his work with lighthouse beacons, Dalén also invented two devices for use with incandescent mantles. One was a mixer that maintained a constant, correct balance of gas and air. The other was a device that made possible the removal of broken mantles and their replacement with new ones.

Dalén also worked on ways to reduce the risks involved in the storage and use of acetylene, a dangerously flammable compound. He filled the casing of the cylinders used in the transport and storage of acetylene dissolved in acetone with Agamassan, or Aga, a porous mixture that absorbs acetylene. Unlike Dalén's mixture, other materials that had been used for filling the casings lacked elasticity, crumbled, and permitted the formation of explosive pockets of the acetylene.

In 1912, while Dalén was testing safety devices used on cylinders of acetylene, he was seriously injured and blinded by a sudden explosion. While he made a good recovery from his other injuries, he remained blind. Despite this handicap, Dalén continued his research. In the following years, he received a number of honors and awards. In 1913, he was chosen for membership in the Royal Swedish Academy. He was also awarded the Morehead Medal by the International Acetylene Association. In 1918, he received an honorary doctorate from Lund University. He was elected to the Academy of Science and Engineering in 1919.

As well as receiving awards and honors, Dalén continued to be valued as a working inventor and engineer. He received the contract for lighting the Panama Canal. Sometime later, he became interested in yet another field of research, thermal technics. His research in this area led him to develop the AGA cooker in 1922. The AGA cooker was a stove requiring only eight pounds of coal to maintain cooking heat for twenty-four hours. The stove was very successful and used throughout the world.

Dalén's son Gunnar eventually succeeded his father in the position of director of Swedish Gas Accumulator. Nils Gustaf Dalén died at his villa in Lidingö, Sweden, on December 9, 1937, at the age of sixty-eight.

IMPACT

Dalén was interested in advancing technology in a wide range of fields. His first inventions were related to farming and included a device for measuring the butterfat content of milk. In the late 1900's, he was involved in the development of a gas turbine combustion engine for use in airplanes. During World War I, he was part owner of an airplane factory that produced approximately one hundred planes. However, Dalén's major impact on research and technology resulted from his work with AGA. His inventions that were the core components of the AGA lighthouse system greatly improved the function of lighthouse beacons. These inventions also enabled lighthouses to function automatically and reduced the cost of their operation. Consequently, the number of lighthouses increased and resulted in greater safety at sea. His AGA flasher system also enhanced safety in railway transportation, as it was used in railroad signals. The safe transportation and storage of the explosive gas acetylene resulted from his work with creating a cylinder to safely contain the gas.

—*Shawncey Webb*

THE AGA LIGHTHOUSE SYSTEM

From 1905 to 1916, Nils Gustaf Dalén developed the AGA lighthouse system. The system required the invention of the following essential components: the AGA flasher with sun valve, the Dalén mixer, and the automatic mantle changer. The term "Dalén light" is used to refer to both the entire beacon system and to the various individual parts.

Dalén had to work in two areas of research to invent a marketable system. First, an automated system had to be able to maintain a fully functioning beacon for an extended period of time. Second, he had to reduce the cost of fueling the system with acetylene, which was preferred for its brightness, and at the same time make the use of the highly explosive gas safe.

Dalén first addressed the problem of the cost associated with a constantly burning light. He developed an intermittent light regulator, the AGA flasher, which reduced the gas consumption by 90 percent. Continuing his research, he invented the sun valve, also known as the solar valve, or Solventil, which used the natural daylight and its absence at night to turn the beacon light on and off. The valve used an arrangement of four metal rods, with a center rod surrounded by three parallel rods. The center rod was blackened and absorbed light; the three surrounding rods were gilt and reflected light. In darkness, all of the rods were of equal temperature and length. When dawn came, the blackened rod absorbed light, thus acquiring a slightly higher temperature and a slightly longer length than the other rods. This triggered a mechanism that cut off the gas supply and extinguished the light. At dusk, the process reversed, causing the gas valve to open, permitting a pilot flame to light the beacon. The combination of the sun valve and the AGA flasher proved extremely economical; it used 94 percent less gas than the continuously burning beacon.

Next, Dalén considered the problem posed by the explosive nature of acetylene. He developed Agamassan, or Aga, a porous mixture of charcoal, cement, asbestos, and water that he placed in the casing of the cylinders containing the acetylene, making its storage safe. Dalén next addressed the need for large lighthouse beacons at sea to have the greatest intensity of light possible in combination with full automation. To obtain the needed light intensity, he used incandescent mantles that required a mixture of acetylene and air at the ratio of one part acetylene to ten parts air, a highly explosive mixture. He invented the Dalén mixer to mix the gas and air at this ratio without danger of explosion. He also invented an automatic mantle changing system. Equipped with a magazine of twenty-four mantles, the changer made a beacon function automatically for a full year without any maintenance. The AGA lighthouse system was the main system used in lighthouses from its first stages of development in 1906 through the 1960's.

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See also: Georges Claude; Martha J. Coston; Fritz Haber; Louis Pasteur.

RAYMOND DAMADIAN

American physicist

Damadian was the first scientist and physician to apply nuclear magnetic resonance technology to diagnostic medicine. His achievements in the field of magnetic resonance imaging are among the most critical advances in medical technology in recent memory.

Born: March 16, 1936; Melville, New York
Also known as: Raymond Vahan Damadian (full name)
Primary field: Medicine and medical technology
Primary invention: Magnetic resonance imaging (MRI) machine

EARLY LIFE

Raymond Vahan Damadian was born in 1936 in Melville, New York, to Vahan and Odette Damadian. The family moved to the Forest Hills section of Queens, where Damadian grew up. As a young man, Damadian studied violin at the Juilliard School of Music and was an avid tennis player. He attended Forest Hills High School, which had an excellent reputation for science and mathematics. In 1952, he won a Ford Foundation scholarship to attend the University of Wisconsin in Madison. There he gave up the violin and competition in Junior Davis Cup-level tennis to major in mathematics and minor in chemistry. By the time he earned his bachelor of science degree in 1956, he had completed all the requirements for medical school. In that same year, he became one of four non-Jewish students accepted to the new Albert Einstein College of Medicine, part of Yeshiva University in New York.

By Damadian's own admission, he was not good at memorizing facts, but he was intrigued by the puzzle-solving aspect of diagnosing disease. Motivated by memories of the death of his grandmother from breast cancer when he was only ten years old, Damadian focused on internal medicine. He soon decided to pursue research rather than clinical work, believing that he could do the most good for the most people by finding better ways of diagnosing diseases rather than by treating them.

Damadian earned his medical degree in 1960 and married one week later. An internship and residency followed at Downstate Medical Center, Brooklyn (now the State University of New York Health Science Center at Brooklyn). During this time, he began to focus on kidney function and in 1962 would begin a postdoctoral fellowship in nephrology at the Renal Division of the Department of Internal Medicine at Washington University School of Medicine in St. Louis, Missouri. This work would eventually lead him to diagnostic magnetic resonance imaging (MRI).

LIFE'S WORK

Damadian began research on membrane sodium pumps. In 1963, he moved to Harvard Medical School's Biophysics Laboratory, where he audited a quantum physics course taught by Edward Purcell that introduced him to nuclear magnetic resonance (NMR) spectroscopy. Before things could go any further, however, Damadian was called to active duty for the Vietnam War. In 1965, as a U.S. Air Force captain, he was sent to the USAF School of Aerospace Medicine, Aerospace Medical Division, at Brooks Air Force Base in San Antonio, Texas. He remained in Texas until his service ended in 1967 and then returned to Downstate's De-

Indomitable

In 1972, Raymond Damadian filed the pioneer patent for magnetic resonance imaging (MRI) technology, titled "Apparatus and Method for Detecting Cancer in Tissue." *Indomitable*, as the apparatus came to be called, consisted of a chamber surrounded by the first human-sized superconducting magnets (later machines would employ permanent magnets or iron-frame electromagnets). MRI technology is based on nuclear magnetic resonance (NMR) technology. In both, when hydrogen nuclei (usually water molecules) are exposed to a strong magnetic field, the nuclei align within the field. The material being scanned is then pulsed with a short radio wave that pushes some of the nuclei out of alignment. The time it takes the nuclei to return to the aligned state is called a relaxation time. Relaxation signals vary in different tissues depending on the composition of nuclei within them. MRI scanners use pulse sequences to produce two scans: T_1 and T_2. Damadian discovered that by moving the magnet back and forth over a surface, it is possible to focus the relaxation signals and locate objects spatially against background information. This technique he called field-focusing nuclear magnetic resonance (FONAR). By using powerful magnets, it was possible to penetrate the human body noninvasively to detect relaxation times from embedded tissues. T_1 and T_2 are used as a diagnostic pair: T_1 provides anatomical details, and T_2 is used for the detection of pathologies. Typically, lesions show up brightly in T_2. By referencing T_2 values to T_1, the lesions can be located and evaluated as to size and invasiveness. Because relaxations are based on inherent cellular chemistry—the response of atoms to a magnetic field and radio pulse—no contrasting agents are required to detect differences in composition.

As nuclei relax, they in turn emit their own radio signals. An MR scanner uses the radio signals emitted from cells to map the body. Relaxation times and density differences account for the contrast and anatomical detail that are unique to MRI and that allow the mapping of soft tissues. This discovery, coupled with the ability to capture the signals emitted, was part of the 1972 patent. Emitted signals can be converted to pixels captured on a screen; the stronger the emission, the brighter the pixel signal and the greater the nuclei component of the tissue. Because every normal tissue has a certain background density associated with it, it becomes relatively easy to detect lesions or defects based on intensity variations from the expected pattern.

Since *Indomitable*, MRI machines have become smaller, cheaper, and more sophisticated, allowing them to be purchased by more medical facilities and increasing their role in diagnostic medicine. Continued refinements in imaging technology only further increase their worth to the medical field. *Indomitable* is now on display at the National Museum of American History at the Smithsonian Institution as a tribute not only to the man who invented it but also to the thousands of patients who have benefited from Damadian's indomitable spirit.

partment of Internal Medicine, Biophysical Laboratory, where he would remain on the faculty for the next eleven years.

Damadian's research indicated that ion imbalances existed in cancer cells, making them chemically different from normal cells. Since this was true, there should be some way to detect the imbalances using chemical analysis. Levels of potassium ions and sodium ions were critical, and from his work he came up with a new theory for how ions are exchanged in living cells. In 1969, he linked his research to NMR spectroscopy, using the technique to successfully map potassium levels inside tissues for the first time. Clear differences were observed between potassium levels in normal tissues and in tumors. Abnormal ion compositions inside cancerous cells resulted in changes to viscosity that could be seen by NMR. Decreased viscosity was found to prolong NMR relaxation times, and these changes were associated with tumor tissue.

In 1970, Damadian further tested the link, comparing NMR relaxation rates between rat normal tissue and rat tumor tissue; tumor tissues showed substantially prolonged rates compared to normal tissues. Relaxation times were elevated regardless of tumor type, and it was further demonstrated that normal tissues showed wide variation in NMR relaxations, which is why they could be imaged so well. This work was published in the journal *Science* in 1971, and it was here that Damadian first proposed the idea for making an NMR scanner that could noninvasively detect cancers in humans.

In 1972, Damadian patented the plans for the first whole-body MR scanner, a machine he constructed with the help of two graduate students, Lawrence Minkoff and Michael Goldsmith. Work began in 1976, and the machine was named *Indomitable* to reflect the struggles overcome during its generation. In 1977, the first-ever whole-body scan of a human was produced. The scan was of Minkoff, the only member of the team small enough to fit inside the machine.

Imaging developments for NMR techniques spanned the 1970's, and refinements to imaging technology continue to this day. Initial imaging was geared to enhancing chemical NMR, but with Damadian's work, imaging became important for picture generation. Richard Ernst developed two-dimensional Fourier MR imaging early in the decade. Paul Lauterbur used magnetic field gradients to make two-dimensional images, and in 1974 Sir Peter Mansfield devised a faster pulse-sequence method for producing images. In 1980, Ernst's work was combined with phase encoding to produce the spin-warp imaging that would dominate the technology.

For all his work in the field, Damadian is considered the father of diagnostic NMR. He holds the pioneer patent for MR scanning, was the first to achieve a whole-body scan of a human, and was the first to produce a commercial MR scanner. Damadian holds more than forty-five patents and in 1978 founded the FONAR Corporation to manufacture MR scanners for commercial sale. Damadian remains active in research on MRI, and FONAR continues to be a leading manufacturer of machines throughout the world.

Damadian has won numerous awards over the years, including the Lawrence Sperry Award (1984), the National Engineers' Special Recognition Award (1985), the National Medal of Technology (1988), the Lemelson-MIT Lifetime Achievement Award (2001), the Benjamin Franklin Medal and Bower Award (2004), the National Inventor of the Year Award (2007), and the Caring Award, presented by the Leslie Munzer Neurological Institute of Long Island (2008). In 1989, he was inducted into the National Inventors Hall of Fame. In 2003, controversy arose when that year's Nobel Prize in Physiology or Medicine was awarded to Paul Lauterbur and Sir Peter Mansfield for their work on the development of MRI techniques. Conspicuously absent to many in the field was Raymond Damadian, the man responsible for the underlying science of MRI.

IMPACT

The impact of Damadian's work cannot be overstated. Magnetic resonance images provide incredible levels of detail far beyond standard X rays, allowing detection of diseases with noninvasive diagnostics. The signal advantage of MRI is that it allows visualization of the soft tissues where a majority of diseases occur; such tissues cannot be visualized with standard X-ray techniques. Further, noninvasive diagnostic techniques are crucial to early detection of disease, as they encourage more individuals to receive testing and early treatment. MRI has been adapted to the diagnosis of various cancers, multiple sclerosis, neurological disorders, cardiac and pulmonary disease, and other soft-tissue diseases.

The FONAR Corporation produced its first commercial scanner in 1980, introducing it to the American Roentgen Ray Society and Radiological Society of North America. In 1981, the first commercial scanners shipped. While *Indomitable* used superconducting magnets, the first commercial scanners used permanent magnets and then later the first iron-frame electromagnets. Scanners have become more technologically sophisticated, physically smaller, and more cost-effective, making them more widely available to hospitals and stand-alone imaging centers. In 1984, FONAR produced the first oblique MRI and in 1985 the first multiangle oblique MRI, both of which increased accessibility to more areas of the body. Damadian's more recent inventions include a full-sized MRI operating room that allows surgeons precise localization information during surgery, and the Stand-Up MRI, which allows physicians to see problems associated with weight-bearing dysfunction, such as pain associated with the spine. The new machine allows imaging to occur through several positions to pinpoint problems.

—*Elizabeth A. Machunis-Masuoka*

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See also: Godfrey Newbold Hounsfield; Wilhelm Conrad Röntgen.

ABRAHAM DARBY

English ironmaster

Darby is best known for his method of using coke instead of charcoal for smelting iron ore, opening up the possibility of greatly enhanced production of cast iron that in turn made possible the construction of modern machinery.

Born: c. 1678; Wren's Nest, near Dudley, Worcestershire, England
Died: May 8, 1717; Coalbrookdale, Shropshire, England
Primary field: Manufacturing
Primary invention: Iron ore smelting with coke

EARLY LIFE

Abraham Darby was the only son of John Darby, a farmer and a producer of nails, who introduced his son to the manufacture of iron products. At that time, nails were generally made from bulk iron by individuals working as craftsmen. By the seventeenth century, nails had proved essential for the construction industry in England. Though builders crafted the houses most often from local wood supplies, they purchased the nails from craftsmen such as John Darby.

The Darby family was Quaker, at a time when Quakers were often ostracized by their non-Quaker neighbors. As a result, Quakers generally did business only within their religious community and maintained a low profile. They were, however, dedicated businesspeople, and those who were merchants sold the products made by their fellow Quakers to society in general. Members of the Darby family were pillars of the local Friends community, and they passed on their allegiance to their descendants.

LIFE'S WORK

As a young teenager, Abraham Darby was apprenticed to Jonathan Freeth, a fellow Quaker and malt mill maker in Birmingham. In 1699, having just finished his apprenticeship, Darby moved to Bristol, where he set up business as a malt mill maker, probably on Cheese Lane. The manufacture of malt mills quickly lost its allure, however, and in 1702 Darby entered into a partnership with three other Quakers making small items of brass used in the manufacture of large tools or machines. The four men founded the Bristol Brass Wire Company, and Darby became the resident manager. In 1704, Darby traveled to the Netherlands, at that time the source of most brass items used in England, to study production methods. Upon returning, he brought several Dutch workmen with him to help develop the company. Darby quickly switched his efforts to casting iron pots. In 1707, he took out a patent (number 380) on a method of casting bellied iron pots, for which there was a huge demand in eighteenth century England. The patent was challenged in court, but Darby won, creating for himself a kind of monopoly.

Darby had been considering moving his business out of Bristol. He formed several new partnerships and in 1708 moved his operations to Coalbrookdale, in Shropshire, where he established both a copper smelter and a brass manufacturing firm and set about mining copper in the area. However, he decided that the future lay in iron, not copper or brass, and these works were wound up in 1713.

Making use of a damaged iron blast furnace at Coalbrookdale, Darby devoted himself to the production of cast-iron pots. He experimented with the production of iron from local iron ore, which turned out to be better suited to the production of cast-iron products than other iron deposits elsewhere in England. Darby poured the liquid iron directly from the blast furnace into molds in the shape of the bellied pots.

As was the practice at the time, the blast furnace was run continuously until the fuel gave out. A sufficient amount of wood was necessary to sustain a months-long run of the furnace, and the wood had to be converted to charcoal. The charcoal was typically transported in panniers carried by donkeys to the vicinity of the furnace, but

IRON MANUFACTURE

Iron ore, from which metallic iron can be extracted, is interlaced with other minerals, namely sulfur and phosphorus. Separating out the pure iron involves intermixing the iron ore with the carbonized fuel, either charcoal manufactured from wood or coke produced from coal. If the temperature is raised to 1,400° Celsius, the pure iron can be separated from its impurities. This high temperature was first achieved in the Middle Ages by the addition of a blast of air (hence, the term "blast furnace") during the process. Furnaces needed to be located near a stream so that a waterwheel could provide power for the blast, and in proximity to deposits of ore and sources of fuel, because the cost of transporting these items any distance was prohibitive. The iron that emerged from the blast furnace could be poured into molds so that it formed "pigs," or ingots.

Pig iron's high carbon content makes it very brittle. For most uses, it has to be further processed after reheating it in a forge to remove impurities. Prior to Abraham Darby's innovation using coke-fueled blast furnaces for smelting iron, few iron products were made directly from cast iron; practically all iron products were made from reworked pigs in which the excess carbon had been removed by reheating and then pounding the pig iron until most of the carbon had been removed. Darby found that cast iron could be used to make cooking pots, which were universally used in eighteenth century England and whose brittleness was not a problem. By setting up a business to produce three-legged cast-iron cooking pots, Darby created for himself a market niche that he and his firm heavily exploited.

Under Darby's son and successor, Abraham Darby II, the business was greatly expanded to produce parts for agricultural plows, steam engines, and cannon, not to mention iron bridges. (Abraham Darby III built the Iron Bridge across the Severn River near his works at Coalbrookdale.) The Darbys were the instigators of industrial iron manufacture in England. The processes they pioneered were later introduced elsewhere in the world and laid the basis for the Industrial Revolution.

lengthy transport tended to break down the charcoal. Thus, blast furnaces were usually located in close proximity to forests. Converting the timber into charcoal was both labor- and capital-intensive, as was transporting the charcoal. By using coke (a derivative of coal) instead of charcoaled wood, Darby was able to produce more than four hundred tons of pig iron in a single season. The average blast furnace, on the other hand, was lucky to produce one hundred tons before its supply of fuel was exhausted.

Unfortunately, Darby became ill at a young age, before he was able to establish his ironworks on a firm footing, and he died on May 8, 1717, at the age of thirty-nine. Fortunately, he had partners in the firm who were able to carry on the business until his son, Abraham Darby II, was old enough to take over the firm. The partners worked in close collaboration with his widow, Mary Sergeant.

IMPACT

Darby's method of using coke instead of charcoal for iron smelting laid the foundation for the iron industry and helped launch the Industrial Revolution. This innovation was certainly influenced by material factors. In early eighteenth century England, the shortage of timber created the impetus to find a cheaper alternative to wood-derived charcoal as a fuel for blast furnaces. However, it was not until the late eighteenth century that the production of iron using coke fuel became widespread.

Using his smelting method to produce widely popular bellied iron pots, Darby created a financially secure business that lasted throughout the century. As an innovative industrialist who created a family firm that continued to dominate the iron industry, Darby became a model for the future leaders of British industry. Once the success of Darby's method became known, many other inventors developed processes that built upon Darby's innovation, so that by the nineteenth century the British iron industry led the world.

—*Nancy M. Gordon*

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See also: Friedrich Bergius; Sir Henry Bessemer; William Murdock; Thomas Newcomen; Robert Stirling.

SIR HUMPHRY DAVY

British chemist

Davy was one of the first men to make a living from the practice of science, as a lecturer and experimenter. He became a shining exemplar of both pure and applied science, by virtue of his discoveries and his adaptations of theory to practice in such devices as the miner's safety lamp.

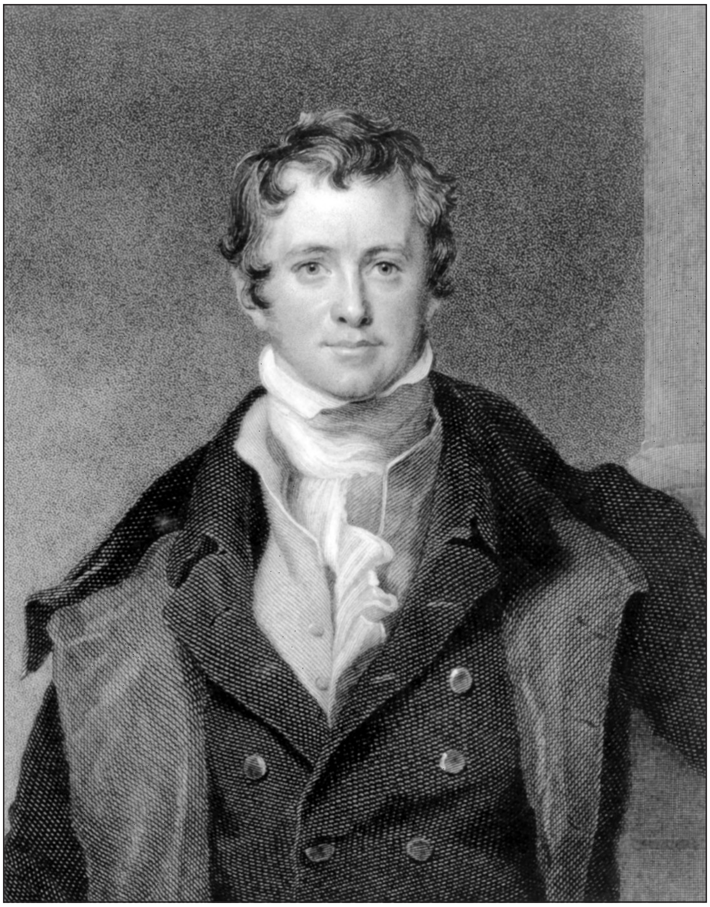
Born: December 17, 1778; Penzance, Cornwall, England
Died: May 29, 1829; Geneva, Switzerland
Primary fields: Chemistry; physics
Primary invention: Safety lamp

EARLY LIFE

Humphry Davy was the eldest of five children of woodcarver Robert Davy and his wife, Grace, née Millett. The Davy family had been prosperous in previous generations, but the only property Robert Davy inherited was a small farm overlooking St. Michael's Mount. His fortunes grew gradually worse; when he died in December, 1794, he left his widow with massive debts. When Humphry was nine, the rest of the family moved to Varfell, and Humphry was taken in by his godfather, John Tonkin, an apothecary-surgeon. Tonkin briefly sent him to school in Truro but then decided he could do a better job of educating the boy himself.

Following his father's death, Humphry's mother opened a milliner's shop in Penzance, which eventually enabled her to pay off Robert's debts; in the meantime, Humphry promised to provide for his siblings as best he could. In February, 1795, he was apprenticed to John Bingham Borlase, an apothecary-surgeon in Penzance, and zealously embarked upon an assiduous course of self-education in science. He was taught to read French by a refugee priest—an accomplishment that enabled him to read Antoine Lavoisier's *Traité élémentaire de chimie* (1789; elementary treatise on chemistry) in 1797; he was much enthused by Lavoisier's account of the newly discovered chemistry of oxygen.

In 1798, Davy caught the attention of a local member of Parliament, Davies Giddy, who subsequently changed his surname to Gilbert and became an important pro-



An 1830 engraving of Sir Humphry Davy. (Library of Congress) moter of science and technology in Cornwall. Giddy gave Davy the run of his own library and a laboratory set up by his physician, then introduced him to Thomas Beddoes, an unorthodox physician who proposed to establish a "pneumatic institute" in Clifton, near Bristol, backed by two prominent members of Erasmus Darwin's Lunar Society, Josiah Wedgwood and James Watt. Beddoes thought that diseases were caused by airborne "miasmas" and intended to experiment with the therapeutic use of "factitious airs" recently discovered by Joseph Priestley, who had discovered oxygen independently of Lavoisier. Although Tonkin was horrified, Davy quit his supposedly safe profession on October 2, 1798, in order to work as Beddoes's assistant.

Beddoes rewarded Davy's boldness by publishing the latter's speculative essay on heat and light, which opposed Lavoisier's hypothesis that heat was an element, preferring to regard it as molecular motion, but argued wrongly that light might be an element capable of entering into molecular combinations. Beddoes had strong literary connections; his sister-in-law was the novelist Maria Edgeworth, and his son, Thomas Lovell Beddoes, later became a significant Romantic poet. Davy also wrote verse and had several poems accepted by Robert Southey for his *Annual Anthology* of 1799, including "The Sons of Genius," in which Davy expressed his hope "to scan the laws of nature, to explore/ The tranquil region of mild Philosophy/ Or on Newtonian swings to soar/ Through the bright regions of the starry sky." Davy also made the acquaintance of Samuel Taylor Coleridge and William Wordsworth, who employed him to see the second edition of *Lyrical Ballads* (1798) through the press and with whom he remained on friendly terms thereafter.

LIFE'S WORK

The research that Davy undertook while assisting Beddoes bore its first fruit when he discovered the exhilarating and narcotic effects of nitrous oxide, which became known as "laughing gas." His first report on his work, *Researches, Chemical and Philosophical* (1799), came to the attention of Count von Rumford (Benjamin Thompson) of the Royal Institution, who offered Davy an appointment as a lecturer. The Royal Institution had recently begun a program of public lectures for artisans and the gentry, and Davy was an immediate success with the latter crowd. He soon won a reputation for extraordinary eloquence and began attracting a celebrity audience, thus initiating the British tradition of the popularization of science.

Rumford's primary research objective at the time—spurred on by the president of the Royal Society, botanist Joseph Banks—was to apply chemistry to the problem of increasing crop yields, in order to make Britain less vulnerable to famine and food shortages caused by naval blockades. Davy became heavily involved in this work, although his first individual project was an investigation of the chemistry of tanning, from which he concluded that tanners had already established a best practice by long trial and error, for which chemistry merely needed to provide a scientific rationale. Banks was so pleased with Davy's work that he became his next patron; Davy was elected a fellow of the Royal Society in 1803 and was appointed as one of its two secretaries in 1807. By then, he was financially independent, one of the first men ever to make a living from scientific practice—a development that prompted William Whewell to coin the term "scientist" to label the emergent profession.

Davy followed up his early intuition about heat by deciding that electricity too must be a force and not a substance, and he became fascinated with its chemical effects. He discovered that electrical batteries could dissociate chemical compounds in solution—a trick that proved extremely fertile in terms of new discoveries. He was able to ascertain that many common substances were formed by the combination of oxygen with metals; by using electricity to dissociate these compounds, he discovered potassium, sodium, barium, strontium, calcium, and magnesium in rapid succession. He also isolated chlorine from muriatic acid and probably tried to repeat his old experiments at Beddoes's pneumatic institute by breathing it in to investigate its possible therapeutic value. His health had already begun to deteriorate, after an attack of "gaol fever" (typhus) suffered in 1908 when he was asked to advise on the ventilation of Newgate Prison, and it continued to get worse thereafter.

Davy was knighted on April 8, 1812, and married a wealthy widow, Jane Apreece, née Kerr (1780-1855) three days later. His research further imperiled his health when he began experimenting with the explosive nitrogen trichloride; an accident that disabled his hand forced him to engage an amanuensis. The assistant he chose, Michael Faraday, became his servant, traveling with him in the capacity of valet on trips to the Continent, which Davy took with increasing frequency. While returning from one such trip via Scotland in 1815, Davy received a letter from the Reverend Robert Gray of Bishop's Wearmouth (now Sunderland) imploring him, as England's leading scientist, to investigate explosions in mines with a view to preventing them. Davy broke his home-ward journey in northeastern England to collect specimens of the gas known as "firedamp," whose chemical makeup he quickly ascertained—it proved to be methane—and whose investigation in the laboratory enabled him to design a "safety lamp" that would prevent it from exploding.

The safety lamp—one of the first great triumphs of "applied science"—completed Davy's fame, all the more so because he refused to patent it, making a gift of the discovery to anyone who might benefit from it. He published a book celebrating the discovery in 1818 and was made a baronet (that is, his knighthood became hereditary—a rather futile gesture, since he was childless) in the same year. In 1820, he succeeded Joseph Banks as president of the Royal Society and celebrated by presenting his researches in electromagnetism to the society in the course of the next two years. He was becoming increasingly irascible, perhaps in consequence of his perpetual ill health, and stubbornly defended his own ideas against those of younger men. He waxed indignant when George Stephenson claimed to have invented a safety lamp before him, but his most serious rift was with his protégé Michael Faraday, whom he had gradually promoted to colleague and collaborator, and for whom he had arranged publication of his early work. When Faraday allowed his own name to be put forward in 1921 for a fellowship of the Royal Society without consulting Davy—presumably for fear of an angry reaction—Davy became infuriated; Faraday went on to revolutionize the science of electricity.

In the hope of overcoming his increasingly troublesome breathing difficulties, Davy undertook further trips to the Continent. After suffering a stroke in December, 1826, he abandoned his scientific work but obtained an unexpected late best seller with a book on his lifelong hobby of fly-fishing, *Salmonia* (1828). While taking a final continental tour in the company of a young medical student, James Tobin, he embarked on a curious valetudinarian study, in the form of a series of philosophical dialogues focused on a cosmic vision, by means of which he attempted to fulfill the final part of the prospectus set out in "The Sons of Genius." He did not complete it, dying in Geneva in 1829, but the extant text was published posthumously as *Consolations in Travel* (1830).

THE SAFETY LAMP

Sir Humphry Davy's careful analysis of "firedamp" not only proved that it was methane but also established the relatively high temperature at which a mixture of methane and oxygen became explosive. It was this measurement that suggested a means of preventing such explosions. He designed a lamp in which gases were fed to and exported from the flame through coiled tubes, which allowed them to cool in transit. This ensured that the lamp could not export enough heat to its surroundings to ignite ambient firedamp. As a further precaution, Davy enclosed the flame within a cylinder of wire gauze, which also helped to dissipate the heat of combustion.

Davy's lamp not only provided miners with safe lighting but also functioned as a firedamp detector; changes in the quality of the flame gave them notice of the gas's presence, enabling them to guard against the asphyxiating effects of the gas as well as its explosive potential, thus saving even more lives. An important item of spin-off from the research program was Davy's discovery that methane and air could combine without an explosion in the presence of a coil of platinum wire—the first example of such a catalytic process to be discovered and a significant example of research in applied science feeding back a significant discovery in "pure science."

IMPACT

Davy was enormously influential in formulating the public attitude to science in the early nineteenth century. He was by no means an uncontroversial figure; along with Joseph Priestley, another scientist closely acquainted with the leading Romantic poets, he was routinely pilloried by the Tory press as a practitioner of "Jacobin science," supposedly affiliated with dangerous revolutionary ideas imported from France. The fact that he became a celebrity and a role model, however, was a godsend to the advancement of British science; he really was a scientific revolutionary, in the best sense of the term.

Davy's discovery of so many new chemical elements resulted from the fact that he was fortunate enough to be in the right place at the right time, but his work in applied science, forging valuable alliances between chemistry, agriculture, and craftsmanship, was much more personal in nature. His brilliance as a popular lecturer was also unique. Although he spoiled his image somewhat by turning on Faraday, he did have some justification for his sentiments in that regard. Some of his guesses proved much better than others, but his enthusiasm to formulate and test bold hypotheses, and his unrelenting intellectual curiosity—still very evident in *Consolations in Travel*—ensured that he became the very model of a questing scientist.

—Brian Stableford

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See also: Charles Babbage; Michael Faraday; Joseph-Louis Gay-Lussac; Joseph Priestley; George Stephenson; Richard Trevithick; Alessandro Volta.

MARK DEAN

American computer scientist

Dean envisioned and built hardware that contributed to the successful manufacture and public acceptance of early personal computers. As an engineer and executive, he advanced information technology to perform diverse functions and process and store vast amounts of data.

Born: March 2, 1957; Jefferson City, Tennessee
Also known as: Mark Edward Dean (full name)
Primary fields: Computer science; electronics and electrical engineering
Primary invention: Microcomputer ISA bus

EARLY LIFE

Mark Edward Dean was born to James and Barbara (Peck) Dean in Jefferson City, Tennessee. His father supervised dams for the Tennessee Valley Authority, and his mother taught in local schools and was a social worker. Dean first attended the segregated Nelson Mary School, where his maternal grandfather, Eugene Peck, served as principal. A mathematically talented child, Dean benefited from advanced lessons in geometry and trigonometry at that school. By third grade, Dean was studying at the integrated Jefferson Elementary.

Dean assisted his father with technical projects at home and saw turbines, generators, and computers that controlled processes at the dams where his father worked. He read *Popular Electronics* and built electronics kits, including a computer. In eighth grade, Dean realized that he wanted to pursue a career in electrical engineering, specifically designing computers for International Business Machines (IBM). Dean lettered in sports at Jefferson High School, where he studied advanced mathematics and earned outstanding grades. He restored automobiles, a hobby he continued to practice as an adult. Dean's family advised him and his younger sister Ophelia, who later became an engineer, to disregard people who discriminated against them. Dean pursued his goals despite obstacles, recognizing that his unique talents were often more valuable to people than their racial prejudices.

After he graduated from high school in 1975, Dean enrolled in the University of Tennessee, southwest of his hometown. Receiving a Minority Engineering Program scholarship, he majored in electrical engineering. He alternated attending school and working for Alcoa Aluminum as part of the university's cooperative program, which was mandatory for minority scholarship recipients. Dean graduated with honors in 1979 with a bachelor's degree in electrical engineering. One of his professors encouraged IBM to hire the young man for a research position at its office in Boca Raton, Florida, where engineers focused on personal computer (PC) innovations. Dean's collegiate experiences shaped his attitude in such a way that, during his career, he provided employment opportunities for minority and female computer scientists and engineers.

LIFE'S WORK

Dean thrived in IBM's professional environment. His colleagues, including Dennis Moeller, encouraged Dean's imaginative approaches to developing IBM's first PCs and expanding their capabilities, starting with the XT (released in 1983). That work resulted in Dean's designing hardware for the AT (1984). He enrolled in night classes at Florida Atlantic University to acquire more technical expertise by pursuing a master of science degree in engineering. Advised by Dr. Alan B. Marcovitz in the Electrical Engineering Department, Dean graduated in 1982. His thesis, "Using a Synchronous System Architecture to Build a Low Cost Graphics Terminal," described how to use cathode-ray tubes to produce and show images.

For IBM, Dean and Moeller created the Industry Standard Architecture (ISA) bus for PCs, their most historically significant invention, which received U.S. Patent number 4,528,626 in 1985. Dean also invented the Color Graphics Adapter (CGA) and a monochrome adapter to enhance PC monitor displays of text and images in black, white, and color. He designed components for the IBM PS/2 Models 70 and 80 and acquired patents assigned to IBM. On March 13, 1988, Dean married Paula Jayne Bacon in Palm Beach County, Florida.

After working ten years in Florida, Dean decided to earn a Ph.D. in electrical engineering to build his IBM career as an administrator and to secure credentials to teach at the university level should the opportunity arise. IBM financed Dean's doctoral work at Stanford University in Palo Alto, California, which he began in 1989. Working with advisers Drs. Mark Horowitz and David L. Dill, Dean wrote a dissertation discussing a computer architecture he designed, titled "STRiP: A Self-timed RISC Processor," to receive his Ph.D. in June, 1992.

Dean next served as advanced systems development director at IBM's Austin, Texas, research laboratory. His work involved designing systems for PowerPC processors and RS/6000 workstation technology. He continued advancing professionally within IBM. In 1995, he

MICROCOMPUTER ISA BUS

Mark Dean considered existing computer bus technology when he designed improved bus architecture for IBM personal computers (PCs) with colleague Dennis Moeller in the early 1980's. Prior to their bus invention, most microcomputers contained a bus with 8 bits, referring to the basic memory unit in a binary number system. Dean wanted to create a 16-bit bus with greater memory capacity. He consulted several patents issued in the late 1970's for relevant inventions, such as "Peripheral Processing System" (number 4,047,158), "Data Transfer Control Apparatus and Method" (number 4,112,490), and "Direct Memory Access Expander Unit for Use with a Microprocessor" (number 4,180,855), developed by engineers for rival computer manufacturers, including Intel Corporation and GTE Automatic Electric Laboratories, Inc.

While working on IBM's PC AT, Dean and Moeller developed what they referred to as the IBM bus. Dean described this invention as a computer containing a central processing unit (CPU), memory, a direct memory access controller (DMA), and a bus interface for peripheral devices to transmit information to the CPU and other peripheral devices as needed. The IBM bus enabled a user to attach simultaneously several external peripheral devices such as monitors, printers, mouse, disk drives, modem, and keyboards to a computer in order for the peripherals to interact with the computer's CPU to perform desired tasks. Dean and Moeller filed this invention's patent application using the formal title, "Microcomputer System with Bus Control Means for Peripheral Processing Devices," in March, 1984. Approved in July, 1985, as U.S. Patent number 4,528,626, that invention's rights were assigned to IBM.

Known commercially as the Industry Standard Architecture (ISA) systems bus, Dean's invention became a basic architectural component in IBM and similar PCs when the PC AT was distributed in the 1980's and other computer manufacturers were permitted to duplicate the ISA's design without compensating Dean, Moeller, or IBM. Because it broadened computing possibilities, Dean's bus contributed to increased consumer demand for PCs and expanded industrial manufacturing of computers and peripheral accessories. Bus applications expanded to support more peripherals such as flash drives and joysticks and to connect computer networks.

By 1986, other inventors had begun referencing Dean's initial bus patent in their patents for bus appropriations. Dean's ISA bus continued to influence inventors' computer architecture concepts through the early twenty-first century. Dean improved his original bus design and utilized bus technology to advance computer technology, receiving additional patents for those inventions, including "System Bus Preempt for 80386 When Running in an 80386/82385 Microcomputer System with Arbitration" (number 5,129,090) in 1988, to stop bus operations when signaled, and "Bus Interface Logic System" (number 5,768,550) in 1995, to coordinate data transmitted by two processors involving several bus transactions.

achieved the status of IBM fellow, which recognized his technical leadership in the corporation. He was the first African American selected for that prestigious title. Promoted to director of the Austin research laboratory in 1997, Dean announced the next year that his engineering team had created a one-gigahertz microprocessor. Dean promoted design plans for a versatile electronic tablet capable of diverse communication and entertainment tasks, but IBM did not develop that idea.

In 2000, Dean accepted the position of systems research vice president for IBM's Thomas J. Watson Research Center in Yorktown Heights, New York. He guided engineers designing architecture of the swift Blue Gene supercomputers for complex biotechnology computations. This work appropriated aspects of cellular microprocessor research Dean had directed in Texas. In 2002, he became storage technology vice president for IBM's Systems and Technology Group in Tucson, Arizona. He contributed to such patented inventions as a magnetic thread data storage device (number 7,206,163). Dean and his wife divorced on June 6, 2002.

Dean's next promotion resulted in his moving to Silicon Valley in 2004 when he became an Almaden Research Center executive in San Jose, California. He led researchers seeking alternatives to hard drives and searching for strategies to fulfill evolving computing needs. During 2007, Dean went to Africa as an IBM Global Innovation Outlook representative to discuss digital technological demands of individuals, companies, and governments. He wrote an article, "Mobile Phone, not PC, Bridges Digital Gap," printed in the *San Jose Mercury News* on February 10, 2008, which stated that wireless technology with diverse capabilities and resources will replace PCs for global populations to have affordable access to digitized information.

By 2008, Dean was serving as vice president of technical strategy and global operations for IBM Research. Interested in medical applications, he contributed his systems experience while overseeing research including computer simulations of such physiological processes as protein folding and a project with scientists from IBM and Stanford University's Center for Probing the Nanoscale enhancing magnetic resonance imaging (MRI) resolution performance to achieve 100 million times more precision than existing MRI technology.

Dean published articles in *IBM Journal of Research and Development* and numerous conference proceedings. He belongs to the IBM Academy of Technology and serves as a board member for the Computer History Museum. A National Society of Black Engineers volunteer, Dean speaks at high schools and colleges about his inventing experiences and African American engineers' technological accomplishments. He and his second wife, Denise, a former IBM executive, reside in Morgan Hill, California. Dean envisions infinite possibilities for technological achievements and continues inventing at IBM and mentoring colleagues, intending to extend his patent tally beyond the approximate forty he had acquired by the early twenty-first century.

IMPACT

Dean designed computers that were the catalyst for the information technology revolution in the late twentieth century. His innovations, specifically graphic display adapters and the ISA bus, improved PC performance and expanded acceptance and use of computers. Within the two decades after PC technology was introduced in the 1980's, computers no longer were confined to laboratories. PCs became standard tools in many businesses and homes, particularly because of features Dean made possible. Widespread use of PCs created employment opportunities in computer design and programming to develop improved systems and software for practical needs and entertainment. Dean's inventions helped generate billions of dollars from sales and salaries to expand and strengthen economies.

Dean's technical skills inspired other computer designers who appropriated his ISA bus design, which was available in the public domain, and built clones of IBM PCs. The computer industry expanded to produce hardware, especially desktops, and such peripherals as scanners, printers, and speakers. Faster microprocessors Dean developed also became broadly incorporated. Dean's inventions for early PCs remained fundamental to twenty-first century computer designs, with approximately ninety percent of modern PCs containing those components. Variations of the ISA concept he invented continued to be incorporated in computers despite alternatives such as the Peripheral Component Interconnect (PCI) bus.

Dean received numerous honors, such as the 1988 *PC Magazine* World Class Award, recognizing his contributions. In 1997, he became the third African American to be inducted into the National Inventors Hall of Fame, and he was presented with the Black Engineer of the Year President's Award and Ronald H. Brown American Innovators Award. Two years later, the National Society of Black Engineers gave Dean its Distinguished Engineer Award. Dean was Black Engineer of the Year in 2000. The next year, the National Academy of Engineering elected Dean for membership. Dean was selected as an Institute of Electrical and Electronics Engineers fellow in 2002. IBM rewarded Dean's contributions with multiple Invention Achievement Awards and Corporate Awards. In 2006, Dean accepted the National Institute of Science's Outstanding Scientist Award. Stanford University named Dean to its Multicultural Alumni Hall of Fame in 2007.

—*Elizabeth D. Schafer*

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See also: Bill Gates; Ted Hoff; Steve Jobs; Steve Wozniak.

JOHN DEERE

American manufacturer

Deere developed a revolutionary steel plow that facilitated agriculture on the Great Plains in the United States, and he oversaw the growth of a company that eventually became a world leader in producing farm machinery.

Born: February 7, 1804; Rutland, Vermont
Died: May 17, 1886; Moline, Illinois
Primary fields: Agriculture; manufacturing
Primary invention: Steel plow

EARLY LIFE

John Deere, the fifth child of William and Sarah Deere, was born in 1804 in the farming hamlet of Rutland, Vermont, where his father worked as a merchant and tailor. William left the family in 1808 for a business trip to England and was never heard from again. Raised by his mother and older brothers, Deere apprenticed as a blacksmith at age fifteen and went to work as a journeyman four years later. Sometime during his apprenticeship, he began courting Demarius Lamb; they married in 1827. For more than a decade, Deere struggled to make his living as a blacksmith, sometimes hiring out to local shops, on other occasions attempting to run his own business. The glut of blacksmiths in the region, however, made it difficult for him to obtain sufficient work to pay off his debts, and fire damaged his shop on more than one occasion. Frustrated and unable to settle his financial obligations, in 1836 Deere sold his business and headed west. His pregnant wife and three young children remained behind, joining him a year later after he had established himself in the town of Grand Detour, Illinois. The tiny settlement on the Rock River needed a blacksmith, and there Deere began what would become a series of business ventures that would transform him from a simple tradesman into the head of a thriving farm implements manufacturing enterprise.

LIFE'S WORK

From the day he opened his shop in Grand Detour, Deere had all the work he could handle. One of the common tasks required of blacksmiths in the region was that

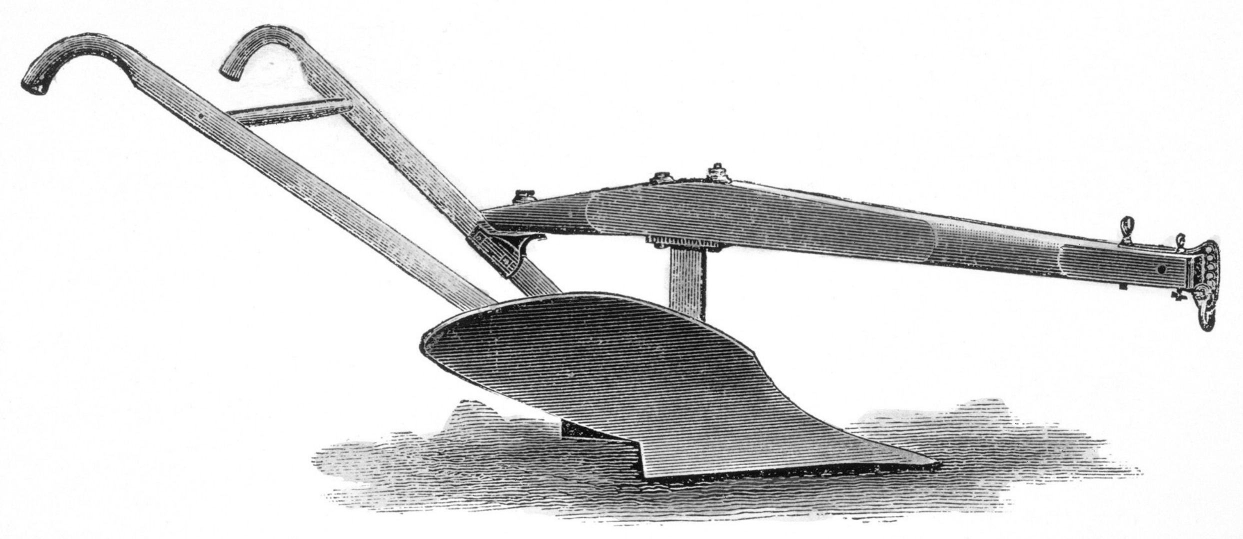

FIG. 2.—Hand plow.

A wood engraving of John Deere's steel plow. (The Granger Collection, New York)

they manufacture and repair farm implements, including plows. In the 1830's, most of the cutting edges on both breaking plows (large instruments used to make first cuts in previously untilled soil) and cultivating plows (smaller ones used to prepare soil for planting) were then being made from wrought iron. Deere discovered that by creating blades from polished steel, he could provide farmers with a tool that would cut through the thick, clay prairie soil without becoming caked up, thus reducing time spent cleaning off the equipment. Deere began manufacturing steel plows in 1837, and for the next decade his skill in producing these implements, coupled with his zeal in promoting their use by farmers throughout the region, allowed him to increase his sales steadily. By 1846, he was turning out a thousand plows a year in his Grand Detour shop. In 1848, he decided to move his operations to Moline, seventy-five miles west on the banks of the Mississippi River. There he built a factory that took advantage of the latest innovations in manufacturing technology, allowing him to grow his business exponentially. Then and later he was aided by a workforce that consisted largely of immigrants who brought with them skills they had learned in Europe and a work ethic that helped the company meet the ever-increasing demand for a variety of plows and other farm machinery. Over the years, Deere developed exceptional loyalty among his workers, who appreciated his hands-on approach to business and his concern for their personal welfare.

Unfortunately, Deere's ability as a craftsman was not matched by a keen business sense. He tried on several occasions to establish partnerships, both in Grand Detour and Moline. At one time or another he was a principal in companies that bore names like L. Andrus and Company; Deere, Atkinson, and Company; Deere, Tate, and Gould; John Deere and Company; Deere and Company; and the Moline Plow Factory. Throughout his years as an active businessman, Deere struggled with credit problems—sometimes as the one in debt but just as often as the one to whom money was owed. He also had to deal with competition that frequently pirated his innovations (although on occasion he, too, was accused of stealing ideas from others), and he found himself involved in numerous lawsuits over patent and trademark rights. The most famous of these lawsuits involved a rival company set up by former associates of Deere who called their business the Moline Plow Company. That name was similar to the one Deere was then using to identify his product, "the Moline Plow." Customers were often confused by the similarity and sometimes sent business to the rival company. In a suit lasting more than four years, Deere finally won a judgment that gave him public credit for his work in developing his special line of plows. An appeals court judge reversed the decision, however, forcing Deere to abandon the generic name for his plow and identify it more closely with Deere and Company.

One of the most significant events in Deere's career occurred in 1858, when his son Charles, who had joined the firm in 1854, became general manager of his father's company. Trained in business and innately adept at management and strategic planning, the younger Deere moved quickly to reorganize operations to take advantage of the growing demand for farm implements not only in the region but throughout the country as well. John Deere's sons-in-law and a few key associates joined Charles in running daily operations. By the second half of the century, Deere's company was selling plows, cultivators, harrows, drills and planters, and even wagons and buggies. John Deere even experimented with development of a steam-driven plow to replace those dragged by animals; unfortunately, this primitive tractor was too far ahead of its time to be of practical value.

In the years after the Civil War, Deere withdrew from active management of the company that bore his name, spending more of his time working his own farm outside Moline and becoming more involved in civic and philanthropic affairs. Although he was designated as president of the newly formed corporation Deere and Company in 1868, he watched from the sidelines as Charles led the firm to a position of national prominence as one of America's leading manufacturing firms for farm equipment. In 1873, Deere and Company introduced a new trademark: the leaping deer. By 1875, company revenues exceeded $1 million, and it had established branch offices in places like Kansas City, St. Louis, Minneapolis, and Council Bluffs, Iowa, to help respond more quickly to the needs of the population in areas far removed from Moline.

Deere's wife died in February, 1865. A year later, he went back to Vermont to marry her sister Lusena, bringing her back to Moline to run his household. In April, 1873, Deere was elected for a one-year term as mayor of Moline, during which he found himself at the center of a battle to impose temperance ordinances throughout the city. He worked diligently to upgrade the city's infrastructure, especially street improvements and fire protection. Deere also found time to make frequent trips back to Vermont and out to the West Coast. In 1885, Deere's health began to fail, and despite trips to resort areas designed to aid in recovery, he continued to decline steadily. He died in May, 1886.

IMPACT

Deere's innovations in the design of plows and other agricultural equipment aided in the emergence of the Midwest as the breadbasket of America. Most immediately, his plow provided farmers a way to till more acreage without having to stop frequently to clean their equipment, which constantly accumulated clods of the sticky soil characteristic of the region. Additionally, Deere's

THE STEEL PLOW

The legend surrounding John Deere's "invention" of the steel plow has many elements of typical American folklore. Ostensibly, Deere took a piece of discarded steel blade from a commercial sawmill, chiseled off the teeth, and shaped the flat steel into a shining plowshare that would slide through thick, sticky prairie soil, creating long, straight furrows. Almost overnight, farmers discarded their old wrought iron plows for those manufactured from steel, thereby creating a revolution in American agriculture.

There are elements of truth in the story, but the actual creation of Deere's plow is somewhat more prosaic. Deere did, in fact, fashion his first plow from a piece of discarded steel. Knowing that midwestern farmers were having to stop frequently to clean off parts of their plows that were constantly being clogged by the heavy black humus they were trying to cultivate, Deere imagined that a plowshare (the cutting blade) and its attendant moldboard (the device that turned over the soil to create neat furrows for planting) might be more effective if made from a material that would resist such contamination. Already familiar with the properties of polished steel, Deere took advantage of the opportunity presented to him by reshaping the steel and fashioning the wooden handles and shafts himself. One of his principal innovations was to shape the moldboard into a parallelogram that permitted the farmer to turn the soil more easily as it was cut.

Properly speaking, however, Deere did not invent the steel plow; others had experimented with steel in constructing plows before Deere manufactured his instrument. His principal contribution was to create a plow that was effective in reducing the amount of clogging farmers experienced when plowing the rich prairie soil. Although the first plows Deere created have been lost, early versions still available suggest he often combined steel and wrought iron in his designs—probably depending on what materials he had available at the time. As he became more successful in his business, he was able to use more steel, which he obtained from mills in the eastern United States. An additional key to his success lay in the combination of inventiveness with a strong belief in the principle of constant improvement. Never fully satisfied with a product once he had begun to market it, Deere was continually consulting with farmers to learn how he might modify his plows to perform even better.

constant effort to improve the quality and functionality of his products led to the development of new and better machines that allowed farmers to cultivate and harvest larger tracts of land. Although not a shrewd businessman himself, Deere managed to surround himself with family and associates who understood how to organize and grow a company in what was sometimes a hostile business climate. Despite his personal limitations, Deere served as a model for those with whom he worked; his determination to succeed as a business owner in a highly competitive market led to the eventual growth of his company into one of the country's leading manufacturing enterprises.

—*Laurence W. Mazzeno*

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See also: Thomas Jefferson; Cyrus Hall McCormick; Jethro Tull.

LEE DE FOREST

American radio engineer and scientist

De Forest's pioneering work in developing the technology for wireless reception paved the way for the development of radio, and his efforts to perfect the process for printing sound on film were instrumental in launching the era of "talking" motion pictures.

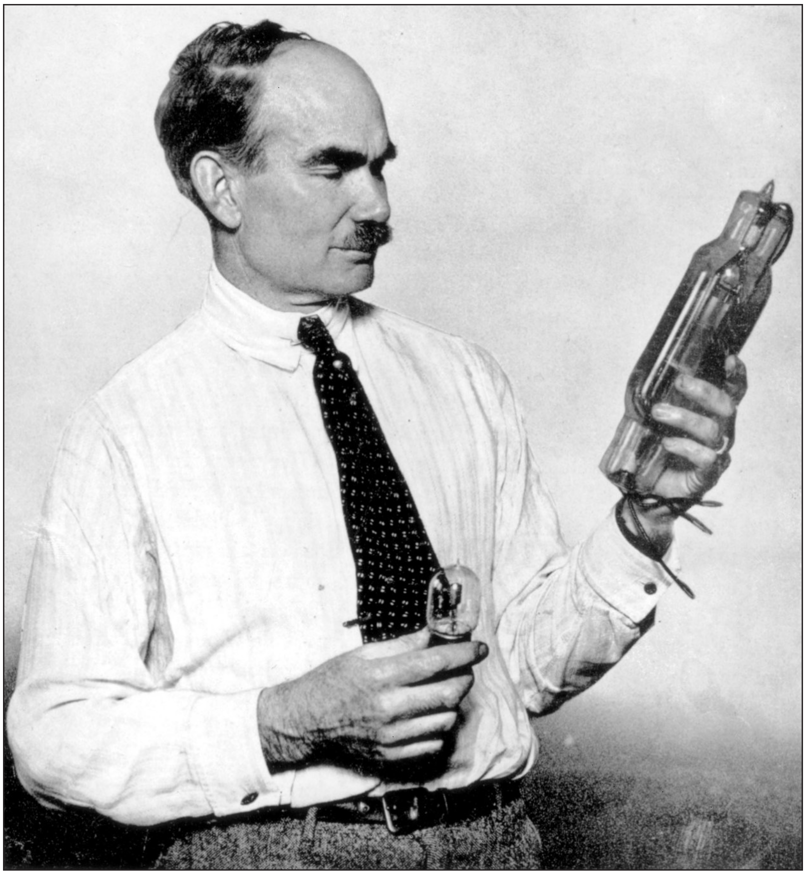
Born: August 26, 1873; Council Bluffs, Iowa
Died: June 30, 1961; Hollywood, California
Primary fields: Communications; electronics and electrical engineering
Primary inventions: Audion (triode vacuum tube); talking motion pictures

EARLY LIFE

Lee De Forest was born in Council Bluffs, Iowa, in 1873, the eldest child of a Congregationalist minister. When he was six years old, his father accepted the presidency of Talladega College in Alabama, an institution founded in 1865 to educate newly freed African Americans. Life in the Deep South was hard on a boy whose family was shunned by the white community, and De Forest spent much of his time on his own. At an early age, he showed an interest in science and engineering, and he was especially fascinated by the work of America's best known inventor, Thomas Alva Edison. When he was seventeen, his father, assuming his son would pursue studies to become a minister, sent him to a preparatory school in Boston to ready him for entrance to a university. In 1893, De Forest entered Yale, but instead of matriculating at Yale College, he enrolled at Yale's Sheffield Scientific School. While an undergraduate, he developed an interest in electricity and electrical engineering. After graduation in 1896, he stayed at Yale to pursue a doctorate. He chose as his dissertation topic a study of the action of short Hertzian waves (radio waves)—exceptionally good preparation for a young man intent on making a name for himself in the newly developing field of wireless technology.

After receiving his Ph.D., De Forest headed to Chicago and found a job with Western Electric, where he proved to be a mediocre employee but an inveterate tinkerer. The new field of wireless communications was just then achieving worldwide attention, as the Italian

Guglielmo Marconi had only recently demonstrated that it was possible to send and receive signals through the air over relatively long distances. De Forest was determined to make his mark in that arena. Though officials at Western Electric saw no future for the company in wireless communications, De Forest spent considerable time (much of it after-hours) developing a responder that might be used to receive sound waves sent from some distance away. Let go by Western Electric in 1900, he spent the next year working as a teacher and translator of scientific publications, devoting his spare time to perfecting the device he called a "Sponder." He considered his device ready for public testing in 1901. With two associates as partners, he set off to make his fortune in wireless telegraphy.



Lee De Forest holds his invention, the triode vacuum tube, or audion. (Getty Images)

LIFE'S WORK

In 1901 at the America's Cup yacht races, De Forest demonstrated to the world the practicability of his responder, transmitting results from the race course to New York as Marconi had done two years earlier. In that year, he organized his first corporation, the Wireless Telegraph Company of America, the first of what would eventually be more than two dozen firms set up to promote his inventions. Although most in the community of inventors and investors were still skeptical of the device's reliability, one man stepped forward to serve as a backer: Abraham White. In 1902, White became De Forest's principal champion, helping organize a number of business enterprises that, in reality, were little more than shell corporations designed to allow White and several unscrupulous investors to take advantage of the notoriety of the new communications medium and De Forest's business naïveté. De Forest was given a modest salary and set up in an office where the public could see him working on his inventions. His principal residence became New York City, where he lived for more than two decades. In 1904, his equipment was featured at the St. Louis World's Fair. All the while, White was making outrageous and sometimes blatantly false claims about the success of the company and De Forest's inventions, selling stock to gullible investors. Little of this income was invested in research; most went to further advertising gimmicks and into White's pockets. De Forest may not have been aware of the extent to which his partner was defrauding the public. The two had a falling out in 1906 when legal challenges were made to De Forest's rights to market some of his equipment. De Forest eventually lost his company and was once again nearly penniless. To make matters worse, in 1906 he entered into a disastrous marriage that lasted only a few months. He would marry and divorce twice more between 1907 and 1928.

By 1906, De Forest had begun experimenting with a new form of receiver based on the work of British inventor John Ambrose Fleming. Convinced that a two-electrode vacuum tube filled with gas could be used to detect and amplify radio waves, he modified one that Fleming had designed and filed for a patent, which was granted in 1906. Not fully satisfied with his device, he continued to tinker with it, eventually adding a third component to his tube, a gridiron-shaped piece of metal inserted between the original electrodes. This tiny piece of metal allowed him to control the flow of electrons in the tube and amplify sounds sent to a listening device. Patented in early 1908, the audion, as De Forest would call it, would be the invention that assured him a place among the world's most important inventors, as it was the device that would eventually allow reception and amplification of the human voice and other sounds—the basis for modern radio.

Curiously, De Forest did not realize the significance of his discovery. Working on wireless technology, he was satisfied that the device provided sufficient amplitude to allow listeners to pick up telegraphic signals sent through the air. Since 1902, De Forest had invested considerable energy and time marketing his wireless system to the U.S. Navy and later to the United Fruit Company. Both organizations saw the benefit of being able to communicate by wireless to ships at sea, and for a time De Forest was successful in raising capital and generating profits from his venture. Unfortunately, the Panic of 1907 had caused investors to look warily at wireless telegraphy, and over the years that skepticism turned into efforts to seek legal recourse against inventors and companies that had not delivered on promises of improved technology and handsome dividends.

THE AUDION

The development of the audion, or triode vacuum tube, has been called one of the most significant technological inventions of all time. While Lee De Forest is generally credited with this invention, his work actually was closely linked to the earlier invention of a diode tube by John Ambrose Fleming and the later creation of a feedback circuit by Edwin H. Armstrong—although De Forest claimed to have been solely responsible for adapting Fleming's diode and for indirectly creating the feedback circuit. Interested in improving receivers for wireless telegraphy, De Forest began experimenting with improvements on Fleming's diode almost immediately after Fleming received his U.S. patent in 1905. In just a little more than a year, De Forest applied for his own patent, claiming his device was notably different from Fleming's and a significant advance in receiving telegraph signals via sound waves sent from locations miles away from his receiver.

Technically, De Forest's audion worked on the principle of radio waves' ability to affect electrical current. The first audion was a diode tube quite similar to Fleming's. It consisted of a gas-filled glass cylinder containing a filament, an arrangement similar to an incandescent light bulb, into which a second metal plate was inserted. The positive terminal of a 22-volt battery was connected to the metal plate, and a pair of headphones added to the circuit; the negative terminal was connected to the lamp filament. Almost immediately after De Forest obtained his first patent for the audion in 1906, he began making modifications to his device. The most significant alternation consisted of the insertion of a thin metal wire, bent in the shape of a gridiron, between the filament and the plate. Doing so allowed him to regulate the flow of electrical current being generated by the action of the radio waves, permitting a continuous flow of electricity and making it possible to "tune" the receptor to achieve greater audibility. De Forest did not progress further with his invention at the time, satisfied that he could receive and detect telegraphic signals with sufficient accuracy to make the audion commercially successful as a receiver for wireless telegraphy. He did take steps to demonstrate how the audion could be used to transmit voice and music, "broadcasting" programs as early as 1907. Soon, a method for achieving sufficient amplification was available, attained by linking a number of audions in sequence. The original headphones were soon replaced by speakers, and the radio industry was born.

In 1912, De Forest and several associates in his new company were sued for fraud. To raise capital, he tried to sell several of his patents to American Telephone and Telegraph Company (AT&T) for $500,000, but AT&T's representative eventually negotiated a deal to purchase them for a mere $50,000. The same story was repeated in numerous instances throughout De Forest's career, as one grand idea after another brought him only a fraction of the millions he thought he deserved for his hard work and ingenuity. Although De Forest was acquitted two years later, he was once again without sufficient financial support to continue as an independent entrepreneur. To make matters worse, his claim to have invented a device to amplify sound was challenged in 1914 by Edwin H. Armstrong, who had developed and patented a similar device two years earlier. The ensuing litigation was not settled until 1926, long after De Forest had lost interest in wireless telegraphy and turned his attention to a new topic, the possibility of producing motion pictures with sound.

Beginning in 1913, De Forest concentrated on perfecting a system for capturing sounds that could be attached in some way to motion-picture film. In his view, this would not only allow viewers to hear actors as they spoke their lines but also permit filming of events such as concerts and operatic performances, which could then be viewed in movie theaters by thousands who for reasons of money or location could not attend live performances. For nearly a decade, De Forest sought ways to imprint sound directly on film, and by 1922 he had managed to do so. In that year, he began demonstrating his new invention publicly. Calling his products "Phonofilms," De Forest recorded speeches, short dramas, symphonies, and operas (including a performance by renowned tenor Enrico Caruso). Unfortunately, he was not able to interest the major movie studios in his process, and since these controlled most movie houses in America, he was forced to show his Phonofilms in small independent theaters. Nevertheless, those who saw his productions marveled at this new phenomenon. It was not long before Hollywood took notice, although studio officials decided not to purchase De Forest's sound-on-film technology. Instead, they opted to develop their own systems, initially settling on one that used a disc for sound that accompanied the film. Once again, De Forest failed to profit substantially from his invention.

As with all his other business ventures, De Forest's Phonofilm Corporation failed to generate sufficient capital to remain solvent. His various radio companies eventually went bankrupt as well, and their assets were purchased by the Radio Corporation of America (RCA). By 1929, De Forest's financial situation appeared dire, and he determined he would no longer try to make a living in New York. In 1930, he moved to California to restart his career as an inventor for the movie industry. He married for a fourth time in 1930, and that union proved lasting.

The last years of De Forest's life brought mixed success. Beginning in 1930 with his election to a one-year term as president of the Institute of Radio Engineers, De Forest waged a campaign against what he considered the overcommercialization of radio during the 1920's. Believing the medium was best used for transmission of high-quality programming with limited commercials, he spoke and wrote against the trend toward excessive advertising and the inclusion of programming that catered to what he considered lower-class tastes (including jazz, which he excoriated on more than one occasion). He declared bankruptcy in 1936 but continued working on inventions and filing for patents on devices aimed at improving movie production and projection. He even developed some rudimentary devices that would eventually be used to launch the television industry. During World War II, he made himself available to the government, assisting the Navy by constructing a terrain altimeter that allowed pilots to determine their positions over the ocean with greater accuracy.

By the 1940's, the radio industry began to acknowledge De Forest's role in launching the medium. He received several tributes, and media began referring to him by the title he had long used to describe himself, the "father of radio." In 1959, he received an honorary Oscar from the Academy of Motion Picture Arts and Sciences for his pioneering work in the industry. All the while, however, he was struggling to make a living by selling some of his inventions and working at various radio schools. Although he was granted more than two hundred patents during his lifetime, none proved substantially remunerative. He never retired, instead continuing to go to his laboratory in Hollywood every day to investigate new ways to improve products and processes for the electronics industry. He died on June 30, 1961, believing (with some justification) that he had played a major role in ushering in the electronic age worldwide.

IMPACT

Determining the true extent of De Forest's contributions to technological advancement requires considerable skill in sorting out myth from fact. Throughout his life, De Forest made great claims for himself as the "father of radio" and insisted that he had done more than any other inventor to advance the development of this new medium. Not everyone agreed with him then or later, and many scientists and historians have downplayed his contributions by pointing out his deficiencies as a theorist. Nevertheless, there is no question that the audion he designed in 1905-1906 and improved in 1907 by adding a grid that permitted better reception and amplification of sound was a key component in allowing for the future development of radio. At the time, De Forest himself did not realize the significance of his invention, and it was not until Edwin H. Armstrong modified De Forest's original design to improve amplification that commercial radio became feasible. In a similar fashion, De Forest's work in perfecting a mechanism for producing talking movies by imprinting sound on film to allow for synchronous transmission of picture and sound was revolutionary. Unfortunately, the major studios refused to work with him or to adopt his technology, choosing instead to develop other methods for generating talking pictures. By the time the movie industry adopted his sound-on-film method years later, the "talkies" had become standard fare at movie houses across the United States.

What is clear, however, is that De Forest's pioneering work in developing the audion made radio possible. Similarly, his efforts to market his Phonofilms during the mid-1920's spurred major movie studios into action to move from silent films to talking pictures, if only as a means of capitalizing on the public's curiosity with the films De Forest was presenting to limited audiences. There is also strong evidence to suggest that De Forest's work with the federal government, particularly the Navy, advanced the military's ability to communicate at sea and conduct air warfare more effectively. While claims advanced by some that he should be considered the "father of the electronic age" may be exaggerated, it is not too much to say that his work was vital to the emergence of new methods of communication that materially improved the lives of American citizens and radically changed lifestyles throughout the country.

—*Laurence W. Mazzeno*

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See also: Edwin H. Armstrong; Walter H. Brattain; Karl Ferdinand Braun; Thomas Alva Edison; Reginald Aubrey Fessenden; Guglielmo Marconi.

SIR JAMES DEWAR

Scottish physicist and chemist

Dewar is probably best known for the Dewar flask, the vacuum flask or bottle used for storing hot or cold substances. He is also a coinventor of cordite, the smokeless gunpowder. Scientists know Dewar best for his research in low-temperature physics.

Born: September 20, 1842; Kincardine-on-Forth, Scotland
Died: March 27, 1923; London, England
Primary field: Chemistry
Primary invention: Dewar flask

EARLY LIFE

James Dewar was the youngest of six sons born to Thomas and Agnes Eadie Dewar. Thomas, owner of the principal inn of Kincardine, the Unicorn Inn, was well respected and was often called on to witness legal papers. Dewar lost his mother in 1852. During the winter of that year, he fell through the ice while skating and contracted rheumatic fever, which forced him to walk with crutches and to miss school for two years. During this time, he developed a love of literature and became friends with the village joiner, who taught him how to build violins. One violin that Dewar built in 1854 was played at his fiftieth wedding anniversary in 1921. (Dewar claimed that part of his skill as an experimenter was the result of the hand dexterity that he developed during this time.) Dewar attended the New Subscription School, where he was a top student before his illness, and continued to excel academically after his bout of rheumatic fever.

Upon his father's death in 1857, Dewar lived with a brother for a time before boarding with Dr. Lindsay, a brilliant teacher at the Dollar Institution, where Dewar flourished under the mentorship. In 1859, Dewar entered the University of Edinburgh, where he earned first-class honors in 1862. Dewar was taught chemistry by Lyon Playfair (later Lord Playfair), who became his doctoral adviser. Dewar's first scientific publication was read by Playfair in 1867 at the Royal Society of Edinburgh, in which Dewar was not yet a member (he would be inducted in 1869). After receiving his degree from Edinburgh, he became an assistant to the new chair of chemistry, Alexander Crum Brown. Crum Brown had developed a method to represent benzene more conveniently than the method used by German organic chemist August Kekulé. Dewar then developed a machine to print Crum Brown's new graphic notation. Playfair sent a copy of the instrument to Kekulé, who invited Dewar to his laboratory for a summer. In 1869, Dewar became a professor at the Royal (Dick) Veterinary College, where he was an effective, enthusiastic teacher. Dewar married Helen Rose Banks in 1871. Their marriage was a happy one.

LIFE'S WORK

Research was Dewar's primary interest. While at the veterinary college in Edinburgh, he introduced himself to John Gray McKendrick. They began a study of the physiological effects of light, discovering that a measurable electrical current is produced when light enters the eye. This effect was studied using eyes from several different animals.

In 1875, Dewar was appointed Jacksonian Professor

THE DEWAR FLASK

The loss or gain of heat energy can occur by several methods. Among those methods are conduction, convection, and radiation. Sir James Dewar invented a container to stop—or at least drastically slow down—heat transfer. He used glass, which is a poor heat conductor. By placing one glass container inside another container, he was able to eliminate the conduction of heat. By creating a vacuum between the two glass containers, he eliminated convection of heat. The vacuum side of the glass containers was coated with silver, allowing the reflection of radiation and thus preventing heat transfer by radiation. Often the two containers were made from the same piece of glass with a small hole to pull a vacuum and to apply the silver coating. A durable container of wood or metal held the glass container. Either wood shims or a small spring held the glass away from the outer container, thus creating another conduction barrier. In modern versions of Dewar's flask, such as the Thermos bottle, plastic is often used for the outer shell.

The Dewar flask was invented to store cold materials. Without the ability to store liquid oxygen or nitrogen for a period of time, the cold liquid was useless for experimentation. Dewar's flasks could be used to store liquids such as oxygen for days and even weeks. However, Dewar did not patent his design, and as a result, the Thermos company was able to profit from Dewar's design with its famous Thermos bottle, which today is used for many types of portable, cold- and heat-preserving storage devices.

Sir James Dewar in 1911. (©Smithsonian Institution)

By the end of 1877, the equipment to produce liquid oxygen had been built in the Royal Institution's laboratory. Dewar even created an optical projector that allowed an audience to watch oxygen become a liquid. Soon he had produced a machine that would generate twenty liters of liquid oxygen per hour. This was easily a sufficient amount to use in experiments to determine properties of materials at low temperature. In one study, Dewar tested the electrical resistance of metals at very low temperatures, finding that the electrical resistance decreased as the temperature was lowered. It was concluded that if the temperature could be lowered to absolute zero, there would be no resistance. Dewar could never reach absolute zero but did achieve temperatures lower than anyone else had at the time. Another study found that seeds that were cooled to liquid nitrogen or liquid oxygen temperatures did not lose the ability to germinate. Dewar also determined the heat capacity of elements at the boiling point of hydrogen (–252° Celsius). He found that liquid oxygen and liquid ozone were attracted to the poles of a magnet.

Without the ability to store liquid oxygen or liquid nitrogen for a period of time, the cold liquid was useless for experimentation. Dewar designed vacuum flasks that could store such liquids for days and even weeks. He did not choose to patent the design, however, and the Thermos company eventually based its famous bottle on his design.

The use of supercooled charcoal as an absorbing agent is another outstanding invention. It allowed metals to be used to build Dewar flasks. Metals continually give off a small amount of gas, which ruins the vacuum needed to produce a good Dewar flask. Supercooled charcoal is an excellent absorber, allowing the retention of the necessary vacuum. In some situations, Dewar used supercooled charcoal to produce a vacuum. Some of his research with the absorbent qualities of charcoal led to its use in gas masks.

of Natural Experimental Philosophy at Cambridge University, where he collaborated with colleague George D. Liveing in a twenty-seven-year partnership that produced seventy-eight papers on spectroscopy. In 1877, Dewar became the Fullerian Professor of Chemistry at the Royal Institution in London. He kept both chairs, dividing his time between Cambridge and London. London had much better research facilities and was the place where his most noteworthy research was done. It was there that he began to work in the field of low-temperature physics. He had to devise the equipment necessary to study the characteristics of materials at low temperatures. It was at the Royal Institution that Michael Faraday had done the initial work on liquefaction of gases.

In 1888, as a member of the Explosives Commission with Sir Frederick Abel, Dewar invented cordite. Cordite is a smokeless powder that became the standard powder used in munitions. Dewar also invented a portable device to carry oxygen. This device was to be used to prevent altitude sickness in soldiers during airplane trips.

When World War I began, the resources and manpower to continue the low-temperature work were not available. Sir Dewar (knighted in 1904) began to study surface tension in soap bubbles. He continued this work until his death on March 27, 1923. In fact, he was at work late one evening just a few days before his death.

IMPACT

Nonscientists are perhaps most familiar with Dewar's invention from the Thermos bottle based on it. This and similar products have made it possible to carry hot and cold liquids to picnics or to work for lunch. Even ice chests to transport food are based on the concept of the Dewar flask.

Dewar's invention has allowed scientists to be able to conduct low-temperature studies. The modern scientist thinks nothing of having a "Dewar" of liquid nitrogen for use in research for a week or more. Sir James Dewar made this possible. Today many scientific instruments use liquid nitrogen to maintain a low operating temperature. This use of liquid nitrogen is possible because containers built on the concept of the Dewar flask can hold cold materials for days and weeks.

More than producing the tools for low-temperature studies, Dewar showed scientists how to conduct low-temperature studies. With John Ambrose Fleming, Dewar studied conduction, thermoelectricity, dielectric constants, and magnetic permeability of metals and alloys at low temperatures. With Sir William Crookes, he studied the emanations from radium. Following the work with Crookes, he worked with Pierre Curie on the gas given off by radium. Dewar opened up the whole new field of low temperature science through his inventions and his leadership.

An area of study related to the Dewar flask was the production of extreme vacuum. The better the vacuum inside the flask, the better the flask was at maintaining the temperature of the material inside. The use of supercooled charcoal as a gas-absorbing material made it possible to use a pump to enhance and maintain the vacuum inside the walls of the Dewar flask.

Finally, Dewar and Abel's invention of cordite made it possible to eliminate the smoke produced by gun cotton. Cordite is an explosive consisting of nitroglycerine and gun cotton in cords or threads. The resulting stable explosive was found to be superior to anything that the British military had previously possessed. The invention of cordite therefore improved the safety of soldiers and vastly improved the ability of commanders to communicate on the battlefield.

—*C. Alton Hassell*

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See also: Sir William Crookes; Michael Faraday; Heike Kamerlingh Onnes; Hudson Maxim; Alfred Nobel.

RUDOLF DIESEL

German mechanical engineer

At the outset of his career, Diesel sought to develop a fuel-driven power source that could replace the unwieldy steam engine. The possibility of internal combustion technology was just emerging. As Diesel's experimentation with pressure-ignited engines evolved, the system that bears his name managed to rival, and even to surpass, fuel-efficiency levels in standard gasoline-powered engines.

Born: March 18, 1858; Paris, France
Died: September 29, 1913; presumed drowned at sea in the English Channel
Also known as: Rudolf Christian Karl Diesel (full name)
Primary fields: Automotive technology; mechanical engineering
Primary invention: Diesel engine

EARLY LIFE

Rudolf Christian Karl Diesel (DEE-zuhl) was born to Theodor and Elise Diesel (née Strobel) in Paris, France. Although both parents were from established German families (he from Augsburg, she originally from Nuremberg), they met in Paris but were married in 1855 in London. They had three children: Louise, born in 1856; Rudolf, in 1858; and Emma, in 1860. Rudolf's childhood and early adolescence were spent in Paris, where his father began a business manufacturing fine leather products. Business difficulties, as well as repercussions of the Franco-Prussian War of 1870, would eventually force the family to move back to Germany in 1877. In the interim, Rudolf was sent to Augsburg, where he studied first in a commercial school and then in the Augsburg industrial school. His experience in the latter school convinced him that he wanted to pursue a career in engineering.

In 1875, he graduated with excellent grades and went on to attend the Technische Hochschule in Munich, where he received enthusiastic support from a well-known professor, Karl Max von Bauernfeind. Another individual who influenced Diesel during his studies in Munich was Carl von Linde, whose lectures focused on the developing industrial use of steam engines. By 1881, Diesel had begun his career as an engineer in the newly founded Paris branch of the German Linde Refrigeration firm. His interest in using compressed-gas technology as a power source in engines was sparked during this time.

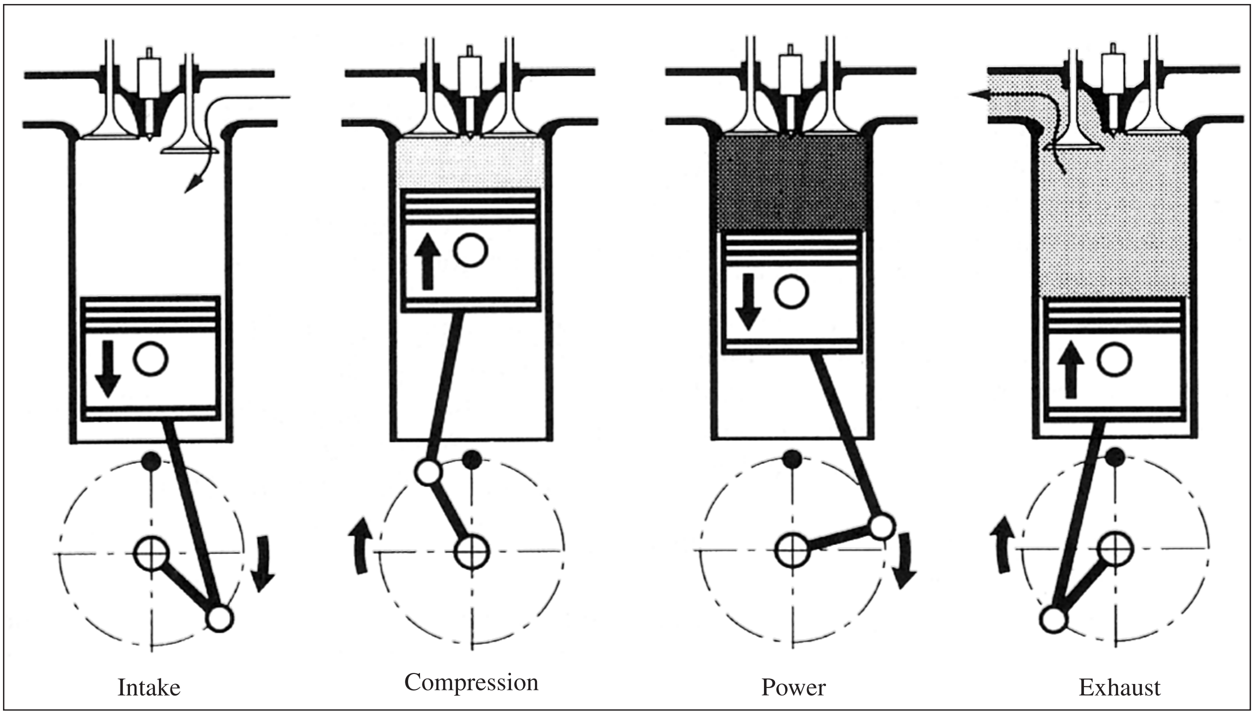
LIFE'S WORK

Between 1881 and 1889, Diesel filled a number of roles as an employee of Linde Refrigeration. Although some of his service, both in France and in Germany, involved work as a sales representative, Diesel's early engineering research was already focused on a main problem raised by his professors: surpassing the efficiency performance—in terms of both fuel consumption and compression levels reached—of the steam engine. Demands of the refrigeration industry already involved procedures for compressing gases and therefore the use of an external engine power source. The challenge was to devise a self-contained power source to provide mechanical energy. Diesel's first accomplishments, for example, were associated with experiments (ultimately unsuccessful) with an internal combustion engine using ammonia vapors.

In 1893, his work gained wider attention when he published a pamphlet titled *Theorie und Konstruktion eines rationellen Wärmemotors* (theory and construction of a rational heat engine). Two important engineering firms, the Krupp works and Heinrich Buz's Augsburg Engine Works, were the first to back his endeavors to design a high-compression engine that, according to Diesel's claims, could obtain more than 70 percent conversion of the heat energy supplied by burning fuel into mechanical power via pistons in an internal combustion cylindrical chamber.

After a few unsuccessful experiences (following rejection of his first request for a patent in 1892), Diesel's report on the product of his work at the 1897 meeting of the German Engineers' Association was followed by his first commercial contract for his engine: Adolphus Busch, the German American head of the well-known brewery, bought the rights to Diesel's U.S. and Canadian patents. The first two-cylinder, sixty-horsepower diesel engine (manufactured in Germany) was installed in the Anheuser-Busch Brewery in 1898. Headquarters of the Diesel Motor Company of America (with Adolphus Busch as president) were set up in the same year in New York City.

Within two years, the industrial prospects of Diesel's engines suddenly became internationally recognized when he won the Grand Prix at the Paris World Fair in 1900. During the 1890's, Diesel had applied his theory of constant-pressure combustion to ignite—that is, explode—fuel to create the expanding energy to drive the



The four strokes of a diesel engine. (Robert Bosch Corporation)

cylinders of his experimental engine. His design used compression ignition instead of the spark-plug technology of the gasoline-powered engine.

As late as 1896, he had achieved only a 54 percent conversion of heat energy into mechanical power, and Krupp almost decided to drop involvement in further development plans. Over the next year, Diesel concentrated his efforts on key improvements: developing a fully unified combustion chamber for both cylinder heads and pistons, and introducing what he called a sieve vaporizer to improve the combustibility of fuel at the point of injection. His success was marked by a striking improvement in the conversion of heat energy into mechanical power, which went up to nearly 76 percent. Pressure ratings within the cylinders reached 34 atmospheres, or 500 pounds per square inch (psi). This surpassed the steam engine's net efficiency (a combination of indices) by a wide margin, although more work had to be done to achieve the mechanical efficiency of steam devices.

Step-by-step improvements brought not only a Grand Prix in Paris in 1900 but also an expansion in the number of patents that could be marketed by Krupp and the Augsburg Engine Works. At this stage, diesel engines were used mainly in heavy industrial applications; the models produced, therefore, were quite large and bulky.

Although the basic engineering principles of diesel engine (fuel combustion induced by high temperatures produced by high compression levels in cylinders) remained essentially the same as the years passed, major efforts went into finding an optimum fuel. Experimentation with fuel substances ranged from liquids derived from soft-coal extracts (used first in American-produced engines) to pure peanut oil, which Diesel's engine used at the Paris World Fair. Some early twentieth century engines used kerosene to start up, switching to pure alcohol for extended (and apparently more efficient) operation. This option was abandoned not only because of the higher cost of alcohol but also because such engines were particularly delicate when fitted with complex fuel injectors and air-density regulator devices. Until late twentieth century energy cost considerations encouraged researchers to return attention to fuels derived from vegetable sources (biodiesel fuels), most diesel engines, with the exception of the huge engines used in oceangoing ships (which used very thick, and safer, "bunker fuel"), were designed to run on very light fuel oils that resemble common kerosene.

One should note that Diesel's business ventures, which

OPERATING FEATURES OF THE DIESEL ENGINE

The major differences between a conventional gasoline-powered engine and a diesel engine lie in the critical process of ignition within the cylinders. In the system developed by Rudolf Diesel, a very high level of air compression is built up in the cylinder before atomized droplets of fuel are injected. High compression—about 40 bar, or some 600 pounds per square inch (psi), compared with about 200 psi in conventional gas engines—heats trapped air to temperatures high enough (about 1,000° Fahrenheit, or 538° Celsius) to ignite injected fuel without the need for an electrical spark.

Diesel's early engines used what are called air-blast injection nozzles. This involved a first-stage compression of fuel using an auxiliary gas engine, creating an atomized mixture at the time of injection. Later solid-injection engines would use a mechanical pump to compress fuel. This simplifies the injection process by using pressure-activated injectors that shoot a concentrated jet of fuel into the combustion chambers.

Diesel engines outperform standard engines in terms of both fuel efficiency and carbon monoxide output. Estimates of diesel fuel efficiency (which stems from the higher density of diesel fuel, which releases more energy per unit of volume than gasoline) suggest savings ranging from 20 to 40 percent compared to gasoline. This efficiency also extends to the critical realm of greenhouse gas emissions. Although diesel emits more greenhouse gases than gasoline, its higher miles-per-gallon efficiency results in less overall pollution.

A recurrent but relatively easily resolved problem associated with diesel engines typically occurs at the time of starting. Because the ignition process depends on achieving high temperature levels as quickly as possible inside each cylinder, it is sometimes necessary to prevent a drop in overall engine block temperature (especially in cold climates) from causing low temperatures in the cylinder walls, which could cause fuel to "gel," or solidify.

Diesel engines routinely require careful internal adjustments to avoid, or at least reduce, the emission of a blue-black smoke. This smoke is emitted usually for a short time while the engine is started because the optimum temperature inside the cylinders has not yet been reached. The phenomenon is more critical, however, if the engine is being "pushed" to higher revolutions per minute than it can accommodate. The smoke emitted in such cases represents lost fuel.

very soon made him a rich man, were founded with the announced intention to reform relations between industry owners and workers—relations that were becoming more and more strained as the industrial age progressed. Diesel made an effort to publicize his views on the subject (including a scheme for some degree of worker-ownership shares) in a book entitled *Solidarismus*, published in 1903, but no effective follow-up (or popular recognition of the book) seems to have occurred.

IMPACT

When Diesel died less in 1913, no one could have predicted that manufacturing and industrial developments in the twentieth century would create a demand for a wide variety of diesel engines, especially in the automotive and trucking industries. Modern diesel engines incorporate a number of improvements to the early models developed by Rudolf Diesel. For the layperson, the most obvious improvements involved increased compactness and efficiency in the fuel-injection stages, making possible the use of diesel engines in passenger cars, a trend that began slowly in the 1930's and expanded rapidly in the last quarter of the twentieth century. Although this phenomenon spread mainly in the sport utility and small to mid-range truck market in the United States, in Europe diesel-powered cars would eventually seriously rival gasoline-powered vehicles. The biggest area of performance by diesel engines is associated with heavy work vehicles.

The most obvious impact of diesel power occurred in heavy-duty transport: rail, buses, and powerful semitrailer trucks used in long-distance hauling. Diesel engines for these vehicles have the highest revolutions per minute (rpm) ranges—about 1,200 rpm, compared with 300-1,200 rpm for average vehicle engines. Huge diesel engines, called "cathedral engines," have been used to power large oceangoing ships.

—*Byron Cannon*

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; John Boyd Dunlop; Henry Ford; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; André and Édouard Michelin; Ransom Eli Olds; Nikolaus August Otto; Stanford Ovshinsky; Sylvester Roper; Ignaz Schwinn; Felix Wankel; Alexander Winton.

WALT DISNEY

American animator, film producer, film director, businessman, and screenwriter

Disney wanted to entertain, not invent, but his expanding vision of entertainment required new technology. Disney began with simple, hands-on devices but ended as head of an innovative research facility designed to turn his visions into reality.

Born: December 5, 1901; Chicago, Illinois
Died: December 15, 1966; Burbank, California
Also known as: Walter Elias Disney (full name); Retlaw Yensid
Primary field: Entertainment
Primary invention: Audio-animatronics

EARLY LIFE

Walter Elias Disney (DIHZ-nee) was the youngest of four sons of Elias and Flora Call Disney, and had a younger sister. His father worked as a carpenter and contractor. In 1906, Elias moved the family from Chicago to a farm at Marceline, Missouri. For Walt, the farm and small town of five thousand people provided freedom and an idyllic vision of cohesive and caring community life that would influence many of his films and even the original Main Street of Disneyland. Although farming was backbreaking work for Elias and his two oldest sons, Walt was allowed to run free, learning a love for nature also evident in his films. He began drawing early and probably saw his first film in Marceline.

Elias was demanding and authoritarian. His two oldest sons fled, and, without them, Elias could not maintain the farm, which he sold in 1910. In 1911, the family moved to Kansas City, Missouri, where Walt's world was transformed, his freedom lost. Elias bought a paper route, paying some children to deliver the papers, but Walt and his brother Roy worked for free. At age nine, Walt rose before dawn, delivered papers, went to school, and delivered more papers after school, holding other jobs for spending money. This rigorous routine may have taught him his obsessive work habits, but it also created the desire for freedom and autonomy that made him resist later attempts to control his career or his studio. Walt was not a good student, but teachers encouraged his interest in drawing. When his family moved back to Chicago, Walt became a cartoonist for his high school paper and attended some art classes. Although underage, he dropped out of high school to join the Red Cross Ambulance Corps. After World War I, he returned to Kansas City.

LIFE'S WORK

Disney briefly worked for the Pesmen-Rubin Commercial Art Studio and the Kansas City Slide Company, while studying animation and unsuccessfully trying to establish his own studio. Bankrupt, he left for California, where he and his brother Roy formed Disney Brothers Studio (later Walt Disney Productions). There, Disney and Kansas City colleague Ub Iwerks (longtime Disney associate, animator, and inventor) produced short comedies for the studio's *Alice in Cartoonland* series. In 1927, Disney began a more popular series, *Oswald the Lucky Rabbit*, but he lost most of his animators and his rights to *Oswald* to his distributor. Angered but undefeated, Disney produced his first internationally successful figure, Mickey Mouse, in 1928.

By then, audiences craved sound. Music and sound effects had accompanied cartoons, but Disney wanted sound that seemed to come from action on the screen. He achieved this in *Steamboat Willie* (1928), with bar and exposure sheets that tied music to screen action. The Silly Symphonies followed. These began with *The Skeleton Dance* (1929) and included the first Technicolor cartoon, *Flowers and Trees* (1932), which won the first Academy Award to be given to an animated film. The virtually plotless symphonies were tone poems integrating sound and action.

The Three Little Pigs (1933) paved the way for a feature-length cartoon. Disney questioned whether audiences would accept animated figures that spoke and sang as if human. To achieve audience identification with characters and their emotions, Disney insisted on a new style of exaggerated realism, rooted in observation of muscles and flesh in real-life action. Animators took art classes and observed wildlife to achieve realistic studies of how bodies move and the effect of gravity on them in motion and at rest. Characters were treated as thinking, living beings. The pigs, distinguished by actions and emotions, not appearance, overwhelmingly demonstrated audience acceptance.

Disney also needed the illusion of depth. Other studios had attempted to produce multiplane cameras, but Disney's studio created the first workable version. It could shoot down through multiple, separately lighted levels of animation. The top levels were basic animation cels; below them were scenic details, and at the bottom was a plain sky or neutral background. As the camera moved, its movements carefully calculated by engineers, different scenic details came into focus. This camera and the new animation style are discussed at length by longtime Disney animators Frank Thomas and Ollie Johnston in *Disney Animation: The Illusion of Life* (1981); they provide both photographs and a diagram of the camera. The device proved effective in the Academy Award-winning *The Old Mill* (1937), a tone poem about an old mill and what happens there on a stormy night.

Walt Disney. (Library of Congress)

With these tools, Disney produced animated film's first full-length feature, *Snow White and the Seven Dwarfs* (1937). The Academy Award-winning eighty-minute film involved some six hundred employees and an estimated quarter million to two million drawings. Attempting to surpass this success, Disney created *Fantasia* (1940), a feature-length development of his tone poems. Philadelphia Orchestra conductor Leopold Stokowski and noted critic Deems Taylor worked with Disney and appeared in this performance of classical music illustrated by animated figures (including Mickey Mouse's appearance in Paul Dukas's "The Sorcerers' Apprentice"). To give the illusion of how music would sound in a concert hall, Disney's studio created Fantasound, an anticipation of later stereophonic developments in its use of multiple speakers and microphones. The sound system was too heavy and expensive for most theaters; Disney hoped for a three-dimensional widescreen production for limited release in better theaters. By this time, however, World War II, raging in Europe, had closed most overseas markets. Eager for immediate profits, RKO Pictures, the distributor, and bankers forced a shortened version into immediate general release; the uncut version was not made public until release of its sixtieth anniversary DVD. The profits from *Pinocchio* (1940) and *Bambi* (1942) were less than expected, and Disney began the worst decade of his adult life.

The 1940's were marked by labor problems, production of war-training films, and financial distress. After the war, Disney turned to television, returning his studio to renewed success; television, its development delayed by World War II, was only then becoming available to the general public. Other studio heads viewed television as a competitive menace, but Disney saw it as a vehicle for advertising his films and financing his new dream, a fantasy-themed amusement park. His television series, under different names, ran for twenty-nine seasons, while he simultaneously pioneered a series of live-action animal films, beginning with *Seal Island* (1948), and, with *Treasure Island* (1950), began live-action adventure films.

In 1952, to provide tools for what would become Disneyland, Disney established WED (his initials), a research and development unit that employed Imagineers—a mingling of animators, story people, set designers, artists, and others—to develop the inventions he would need. WED produced the audio-animatronic robotic figures that populated Disneyland and the 1964-1965 New York World's Fair. Disneyland opened on July 17, 1955, and attracted 3.6 million people its first year. At the time of his death, Disney was planning Florida's Disney World and envisioning the Experimental Prototype Community of Tomorrow (EPCOT), a futuristic city that was never built.

IMPACT

Winner of more than thirty Oscar and Emmy awards and recipient, in 1964, of the nation's highest civilian honor, the Presidential Medal of Freedom, Disney possessed an unusual gift for storytelling and a rare understanding of the emotions and dreams of popular audiences, combined with an obsessive concern for detail, equally obsessive work habits, and a belief that hard work and imagination could solve all technical problems. Repeatedly, those who worked with him, while acknowledging that he could be difficult, marveled at his ability to spread his enthusiasm and to find people's previously unknown talents. Never content unless a new effort was superior to his last, Disney transformed an originally small studio into the world's best-known name in popular entertainment. From development of internationally recognized cartoon characters through films popular in repeated reissue, his drive was toward animation and later live or robotic action that was both realistic and emotionally appealing. This forced him to imagine the inventions needed to realize his dreams and create the research facilities to provide them. His animated cartoons, animated and live-action feature films, and first theme park, as well as the establishment of WED, also ensured that his vision would be continued after his death.

—*Betty Richardson*

AUDIO-ANIMATRONICS

In 1949, while visiting New Orleans, Walt Disney bought a mechanical bird. Imagining the possibility of three-dimensional animation, he sent the bird to his machine shop to see how it worked. This was the start of audio-animatronics, the robotic devices that provided the illusion of reality at Disneyland and the 1964-1965 New York World's Fair. From the bird, he moved on to a dancing figure and then to a barbershop quartet. At the beginning, these were crude devices, capable of only simple, repetitive movements. They rested on cabinets containing large drums. As the drums turned, cams moved levers that in turn connected to the wires that moved the figures. A movie projector on the cabinet's floor moved the drum while providing a synchronized sound track. The first major application was in Disneyland's Enchanted Tiki Room, where birds, flowers, and tiki gods performed. A convincingly real robotic robin sang along with Julie Andrews in Disney's 1964 hit musical *Mary Poppins*.

By then, audio-animatronic figures had become popular features of the New York's World's Fair. Disney's Abraham Lincoln, created from an 1860 life mask, rose, gestured, and spoke; he was the most sophisticated such figure to date. Solenoid coils inside the head governed facial expressions, hydraulic and pneumatic valves controlled body motions, and Duraflex created a realistic skin. Frames of movement were recorded on reel-to-reel audio tapes, which, when played back, triggered mechanisms that caused the figure to move. Words, music, and special effects were synchronized. (Audio-animatronic figures were computerized after Disney's death.) Other audio-animatronic figures appeared in the Pepsi/UNICEF It's a Small World show and General Electric's Carousel of Progress. It's A Small World took boatloads of spectators through different regions of the world where children, modeled to look alike except for skin color, played and sang representative songs. The General Electric exhibit featured a stationary stage around which the seated audience moved. The audience saw four households set in the late 1800's, the 1920's, the 1940's, and the 1960's, each demonstrating how electricity has improved everyday life. The WEDway People Mover, Disney's proposed mode of mass transportation, transported spectators in automobiles through a series of scenes from prehistoric times with audio-animatronic dinosaurs to a space city of the future.

Audio-animatronics had already proved successful at Disneyland. The popularity of the World's Fair exhibits guaranteed the success of the Orlando, Florida, theme park, then being planned at the time of Disney's death.

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See also: Nolan K. Bushnell; Joshua Lionel Cowen; William Redington Hewlett; Steve Jobs; Paul Winchell.

CARL DJERASSI

Austrian American chemist

Djerassi synthesized norethisterone, the first and most widely used oral contraceptive. He has also contributed to the fields of steroids, antihistamines, alkaloids, antibiotics, anti-inflammatory agents, terpenoids, sponge sterols, and physicochemical techniques. He is a published poet, novelist, autobiographer, and playwright, and he originated the genre that he calls "science-in-fiction."

Born: October 29, 1923; Vienna, Austria
Primary field: Chemistry
Primary invention: Birth control pill

EARLY LIFE

Carl Djerassi (djeh-RAH-see) was born on October 29, 1923, the only child of Samuel Djerassi, a Bulgarian physician, and Alice Djerassi (née Friedmann), an Austrian dentist. Both his parents were Jewish but were not observant, and Carl has described himself as a "Jewish atheist." He attended the high school (*Realgymnasium*) that Sigmund Freud had attended. His parents divorced, and he spent most of his time with his mother in Vienna and summers in Sofia with his father. After the Anschluss (Nazi Germany's annexation of Austria) in 1938, his father remarried his mother so that she and Carl could procure Bulgarian passports and immigrate to the United States.

In December, 1939, mother and son reached New York City with little money. Carl attended two semesters at Newark Junior College. With the chutzpah characteristic of an immigrant unfamiliar with how to obtain a scholarship, Djerassi wrote to Eleanor Roosevelt, who forwarded his letter to a foundation that awarded him a scholarship for the spring, 1941, semester to Tarkio College in Missouri. He spent two semesters and a summer at Kenyon College in Gambier, Ohio, receiving his A.B. summa cum laude at age eighteen in 1942.

For a year, Djerassi became a junior chemist at CIBA Pharmaceutical Products in Summit, New Jersey, where he cosynthesized pyribenzamine (tripelennamine), one of the first antihistamines and a popular drug for allergy sufferers. In 1943, he obtained a fellowship at the University of Wisconsin, where he worked with steroid chemist Alfred Wilds. Djerassi converted testosterone, the male sex hormone, to estradiol, the female sex hormone, which had previously been extracted from large amounts of pregnant mare's urine. He received his Ph.D. degree in 1945 at age twenty-one. He returned to CIBA (1945-1949), resuming his research on antihistamines and steroids.

Impatient, independent, and unconventional, Djerassi at age twenty-five hoped to establish his reputation on research publications and then enter academia later in a more advanced position. Cortisone was considered a wonder drug for arthritis and inflammatory diseases but was incredibly expensive since it required a thirty-six-step synthesis from deoxycholic acid prepared from cattle bile. Djerassi entered the international race begun at several universities and pharmaceutical firms to prepare this rare hormone from more available sources.

LIFE'S WORK

In 1949, George Rosenkranz, scientific director of Laboratorios Syntex S.A. in Mexico City, offered Djerassi an associate directorship of research to try to synthesize cortisone from diosgenin, a steroid sapogenin readily extracted from the tubers of *Dioscorea*, an inedible Mexican yam. Djerassi had never heard of Syntex, and Mexico was not known for research, but he thought that he and the company had a common goal—to establish a scientific reputation.

In a tour de force of less than two years, Djerassi, Rosenkranz, and coworkers divided into two groups and won the race to synthesize cortisone. A few months later, they reported a second synthesis, from hecogenin, another sapogenin from the waste products of Mexican sisal, an *Agave* hemp plant. Their success was touted in leading magazines and put them on the "international steroid map."

In 1951, Syntex was the only firm that could synthesize progesterone, the female sex hormone, in large amounts from diosgenin obtained from Mexican yams. However, none of their syntheses ever contributed directly to treating a single arthritic patient. Within a few months, the Upjohn Company, employing a combined chemical-microbiological method, succeeded in converting the female sex hormone progesterone to cortisone in high yield and by the shortest synthesis, and Syntex became the major supplier of raw material for the synthesis of cortisone.

Because progesterone, which Syntex was then preparing in large amounts, was known to inhibit ovulation, thus preventing a pregnant woman from being fertilized again during pregnancy, it could be considered as nature's contraceptive. Djerassi's team synthesized 19-norprogesterone, which was found to be four to eight times as active as natural progesterone, which was the most effective progestational hormone. They succeeded in producing 19-nor-17 alpha ethynyltestosterone. They submitted it for biological evaluation, which showed it to be the most potent oral progestin then known. Because Syntex had no pharmaceutical outlets or biological laboratories, it chose Parke-Davis to market the drug under the trade name of Norlutin after receiving approval from the U.S. Food and Drug Administration in 1957. It is still one of the two most widely used oral contraceptives.

The international acclaim that Djerassi garnered for his steroid and contraceptive research brought him what he had long sought—an academic position. In 1952, he became a tenured associate professor at Wayne University (now Wayne State University) in Detroit, Michigan. He became full professor the following year. During his five years at Wayne, he initiated the research that he considered his most important contribution to chemistry, the application of physicochemical techniques to characterize and determine the structures of organic compounds, which have become standard methods.

Carl Djerassi poses with his wife, biographer Diane Wood Middlebrook, outside their home in July, 1991. (Time & Life Pictures/Getty Images)

THE PILL

Carl Djerassi was inducted into the Inventors Hall of Fame in 1978 for his discovery of oral contraceptives (U.S. Patent number 2,744,122; filed November 22, 1951). He considered his two years at Syntex (1949-1951) "among the most productive ones of my chemical career," since less than half a year after his synthesis of cortisone, he synthesized the first oral contraceptive.

In 1921, Ludwig Haberlandt, an Austrian endocrinologist, proposed that extracts of corpus luteum (Latin for "yellow body"), which produces progesterone, a steroid hormone involved in the female menstrual cycle and the embryogenesis in the body of humans and other species, could be useful for birth control. It was only weakly active when taken orally, so daily injections were needed. Paul Ehrlich established relationships between biological activity and chemical structure that enabled scientists to predict which drugs might be useful.

Using these principles as guidelines, Djerassi, George Rosenkranz, and their team sought to modify the progesterone molecule to form an orally active substance with its biochemical properties. On October 15, 1951, Luis Miramontes, their young undergraduate chemistry student, synthesized 19-nor-17 alpha ethynyltestosterone (generic norethisterone). Several weeks later, the team filed their patent application for this compound that became one of the first ovulation-inhibiting ingredients of oral contraceptives. Djerassi reported their results at the April, 1952, American Chemical Society meeting in Milwaukee, Wisconsin, and they published their article three years later in the *Journal of the American Chemical Society*. After clinical studies by Gregory Pincus and others, the U.S. Food and Drug Administration (FDA) approved the use of norethindrone, now one of the world's most widely used steroid contraceptives. According to Djerassi, if these drugs had been discovered two decades later, they would not have been approved because of more stringent FDA regulations.

In view of the pill's extensive use, considerable clinical research on possible side effects made it the most intensively studied drug in modern medicine. By the close of the 1960's, evidence of an increased risk for strokes, cardiovascular disease, and blood clots were ignored but were later exaggerated. The risks were reduced considerably by decreasing the amounts of the progestin and estrogen components, and the pill was found to reduce the risk of ovarian and endometrial cancers. For healthy young women, the benefits of the pill more than outweigh any risks, making it the most effective and probably the safest contraceptive.

An ardent feminist since his third marriage, Djerassi has described himself as the pill's mother and Gregory Pincus, who "fertilized" norethindrone, as the pill's father.

Djerassi returned to Syntex for a second three-year term as vice president for research. In 1959, he became professor of chemistry at Stanford University, and he became professor emeritus in 2002. He retained his ties to industry and served in important positions with Syntex, Zoecon, and other firms.

While in Mexico, Djerassi had become interested in natural products obtained from the giant cactus, which led him to determine the structures of hundreds of alkaloids, terpenoids, and other natural products. He also worked on artificial intelligence and on the biosynthesis and biological function of sterols and phospholipids in marine animals. He has served as a mentor to hundreds of graduate students and postdoctoral fellows.

In 1965, Djerassi and Dale and Pamela, the two children of his second marriage, which ended in divorce in 1976, bought some undeveloped land in the Santa Cruz Mountains, which he called SMIP, for "Syntex made it possible" (later, during the Vietnam War, for *sic manebimus in pace*, "thus we will remain in peace"). He purchased additional land; by 1972, he had twelve hundred acres, which he converted into a cattle ranch.

On July 5, 1978, Pamela, an artist suffering from depression, committed suicide. Djerassi called this "the greatest tragedy of my life." He decided "to create something living out of a death . . . patronage of the type that would have benefited Pami." He and his third wife, Diane Middlebrook, a biographer, poet, and Stanford professor, whom he had married in 1979, established a colony for women artists at the SMIP ranch. Expanded to include artists, composers, writers, choreographers, and poets of both sexes and administered by the nonprofit Djerassi Foundation, this resident artists program has supported some fifteen hundred artists.

In summer, 1985, Djerassi underwent an operation for cancer, which forced him to come to terms with his own mortality. He decided to embark on a third career (after his scientific careers in industry and academia) in creative writing. Under Diane's influence, he was transformed from a traditional "uptight" research scientist to a more emotionally open novelist, poet, and playwright, specializing in what he calls "science-in-fiction," as opposed to science fiction.

A winner of numerous awards, Djerassi is one of the few American scientists to receive both the National Medal of Science (for the first oral contraceptive, 1973) and the National Medal of Technology (for promoting new approaches to insect control, 1993).

IMPACT

Djerassi's name is virtually synonymous with "the pill," the first and most widely used oral contraceptive, based on the steroid norethisterone (or norethindrone), which he synthesized. This discovery and application changed the world by separating the act of sex from reproduction, ushered in the sexual revolution of the 1960's, and led to the further emancipation of women. In fact, history can be divided into the pre-pill and post-pill eras. In what has been characterized as a "golden age" in pharmaceuticals, the pill's biological consequences engendered profound changes in society and religious, political, economic, and cultural attitudes on the pill's acceptance and use.

An award-winning scientist, Djerassi carried out fundamental and significant studies on organic, physical, and steroid chemistry and spectroscopic methods for the characterization and identification of chemical compounds. Beginning in the late 1990's, he became a true Renaissance man by completing half a century of dual research careers in industry and academia and dedicating himself to a new, third career in creative writing along two lines, one fictional and one autobiographical. His short stories, novels, poetry, and plays have won critical acclaim, and he has championed the science-in-fiction genre.

—*George B. Kauffman*

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See also: Percy Lavon Julian; Max Tishler.

HERBERT HENRY DOW

American chemist

Dow's work in developing processes for extracting chemicals from brine and combining chemicals into compounds with commercial potential helped establish the chemical industry in America and led to the development of hundreds of products that improved Americans' lives and raised the country's standard of living.

Born: February 26, 1866; Belleville, Ontario, Canada
Died: October 15, 1930; Rochester, Minnesota
Primary field: Chemistry
Primary invention: Method for extracting bromine from brine

EARLY LIFE

Herbert Henry Dow was born on February 26, 1866, in Belleville, Ontario, Canada, where his father had recently moved from New England to oversee operations in a sewing machine factory. The job did not pan out, and the Dows moved back to New England until 1878, when they relocated to Cleveland, Ohio.

Dow graduated from high school in 1884 and enrolled in the new Case School of Applied Sciences (later to become a part of Case Western Reserve University). For his senior thesis, Dow decided to investigate a process for chemically extracting various elements from brine, saltwater residing in pools below ground throughout the Midwest and filled with trace elements of bromine, chlorine, calcium, and magnesium. Dow was particularly interested in capturing bromine, because bromide compounds were being used in the production of pharmaceuticals and photographic supplies. At the time, bromine was being obtained by first boiling the brine to allow the salt to crystallize, then mixing chemicals into the remaining solution to separate the bromine. Dow was convinced he could capture bromine directly from brine without evaporation, speeding up the process of extraction and eliminating the need to dispose of tons of salt, the commercial value of which fluctuated widely.

After graduating from Case in 1888, Dow moved to Canton, Ohio, where he set up a company to put his theories into practice. Although his initial effort failed to bring commercial success, he was convinced of the efficacy of his processes. In August, 1890, he moved to Midland, Michigan, site of the largest underground brine sea in the country. With financing from a group of Cleveland businessmen, he set up the Midland Chemical Company, building a small plant to extract bromine from brine and process it for commercial sales. Although he worked at the plant almost incessantly, he took time in 1892 to marry Grace Ball, a local schoolteacher, with whom he would have four children.

LIFE'S WORK

Dow's early efforts to combine his work as a researcher and businessman were not particularly successful. In 1892, he reorganized his company, obtaining financing from several new company directors who turned out to be less interested in experimentation than in making money from proven methodologies. Hence, Dow's decision to switch from manufacturing ferric bromide to potassium bromide pleased his directors when it led to increased profits for the company, but his insistence on spending time looking for other ways to use the brine solution when the company was doing well led to his dismissal as Midland Chemical's general manager. Dow returned to Ohio briefly to perfect a method for extracting chlorine from brine, but by 1896 he was back in Midland. New sources of financial support allowed him to build a new plant and organize the Dow Chemical Company in May of 1897. The firm had difficulties initially, but within three years Dow Chemical was so successful selling chlorine bleach that it absorbed Midland Chemical and became the country's principal supplier of a number of chemical products. Though his investors realized handsome dividends, Dow insisted that a portion of profits be invested in plant improvements and continuing research. In 1900, he instituted what was then a revolutionary practice: a profit-sharing plan for his employees to allow them to benefit from the company's continued growth.

In 1902, Dow fought off a challenge from British manufacturer United Alkali, the world's largest manufacturer of bleach, to drive him out of the bleach market. Buoyed by that success, Dow determined to begin exporting bromides to Europe. At the time, the worldwide market was controlled by a cartel of German companies that had already seen their U.S. sales adversely affected by Dow's emergence as a major supplier in America. In 1904, the German cartel informed Dow that he must cease efforts to export bromine or face economic repercussions.

Dow refused to cave to pressure, and for four years his company engaged in a price war with the German firms who dumped bromine on the American market, charging as little as 10.5 cents per pound—well below production costs. These companies maintained a much higher sales price in Europe in order to keep their operations solvent, so to compete with them Dow bought imported bromine at the discounted price, repackaged it, and sold it in Europe at the going rate there. Finally, in 1908, the German companies proposed a new arrangement whereby Dow would control the American market but not export to Germany; other parts of the world would be available for open competition. For the first time in history, an American firm had actually bested the German chemical giants, and when the Germans proposed a similar arrangement to Dow for sharing the chlorine market, he was able to turn down their offer, confident that he could compete by producing his products more cheaply while maintaining high quality. Surprisingly, in 1913, at a point when sales for chlorine bleach were at a peak, Dow announced that the company would move away from manufacturing that product—presumably because he saw that competitors would eventually be able to challenge Dow Chemical's undisputed prominence in that field.

During World War I, as Germany's relations with the United States became increasingly more hostile, it became exceedingly more difficult to import products from that country. The problem turned out to be a boon for Dow, who discovered that he now had new markets for some of his products and additional markets for ones he had only recently begun to develop. One of the principal new lines Dow Chemical produced during the war was synthetic indigo dye, an item in high demand in the clothing industry. Dow was convinced that another derivative from brine, magnesium, had a future as part of an alloy replacing steel and even aluminum. Its light weight made it appear to be perfect for aircraft and automobiles, but Dow was unable to convince manufacturers to use magnesium alloys during the war. Only years later, during World War II, did magnesium alloys become a major component in aircraft construction. Dow managed to sell a small amount of magnesium to the government, as it was an important component in making flares. He also found himself serving as a major supplier of phenol, a component critical for manufacturing explosives. Shortly before the United States entered World War I in 1917, government representatives asked Dow to participate in manufacturing poison gases. Reluctantly, he provided space and personnel for research and development, and ultimately tear gas and mustard gas were produced at the Dow facility. Fortunately, none of these products were ever used by the United States on the battlefield.

By the end of the conflict, Dow Chemical was an undisputed leader in chemicals manufacturing, offering a wide diversity of products for a variety of industries both at home and abroad. Although Dow was forced to lay off much of his workforce immediately after the armistice was declared, the company soon returned to profitability,

EXTRACTING BROMINE FROM BRINE

Work on his senior thesis at the Case School of Applied Sciences convinced Herbert Henry Dow that there were potentially vast profits to be made from extracting trace elements such as bromine from the brine that lay beneath the ground throughout the Midwest. He also realized that it would become increasingly more expensive to extract those elements using current technology, which required that the brine be boiled as a first step in the extraction process, because fuel for boiling was becoming scarce in the region. Dow reasoned that he could capture bromine through a process he called "blowing out." First, using chemicals such as calcium hydroxide, calcium chloride, and calcium hypochlorite to oxidize the cold brine, Dow dripped the brine solution over burlap sacks. He then passed a current of air across the sacks, blowing out bromine gas. He arranged to have this gas come into contact with scrap iron, causing a chemical reaction that produced ferric bromide, a substance with an established market for sales. Later, he would modify his mixture, adding potash to create potassium bromide, a product in even higher demand.

Although Dow conceived the theory for extracting bromine from cold brine while still an undergraduate, it took him several years after graduation to transform his ideas into a workable mechanism that could produce bromide compounds in sufficient quantity to allow him to run a profitable business manufacturing them. Nevertheless, once Dow had perfected his blowing-out process for treating the cold brine, he began experimenting with another method for extracting bromine: electrolysis. To supplement the blowing-out process, an electrical current was passed through the oxidized brine, speeding up the process of collection. Working diligently in his laboratory, Dow developed a mechanism for carrying out this theory as well. His major accomplishment, however, was to extrapolate his laboratory practices to machinery that allowed him to treat millions of gallons of brine solution and extract tons of bromide compounds, making it possible for his company to become commercially successful.

largely because Dow had continued his practice of product diversification. Over the next decade, the company began producing dozens of new products, including aspirin, which was sold to others who marketed the product under their own brand names. In 1922, Dow led efforts to gain some tariff protection for the American chemical industry, ensuring his company a level playing field with European competitors. Meanwhile, the men Dow had hired as his chief lieutenants during the company's first twenty years were spearheading sales, research, and production at the Midland headquarters and offices in other American cities, operating on the principle Herbert Dow had articulated during the company's infancy: Dow Chemical would make a product only if it could do so better and more economically than any competitor.

After the war, Dow turned his attention to the automotive industry. For some time, he concentrated on creating a new magnesium alloy for use in making automobile parts. The pistons he created showed promise in race cars, but fears that magnesium was highly flammable kept automobile companies from adopting Dow's parts on a wide scale. He did achieve great commercial success with a new fuel additive, tetraethyl lead, a product with high bromine content. This product prevented "knocking" in automobile engines, allowing them to run more smoothly. The exceptionally high demand for tetraethyl lead drove Dow Chemical to explore ways to extract bromine and other chemicals from seawater, a project that proved commercially successful in 1934. Unfortunately, Herbert Dow did not live to see this new advance. He died on October 15, 1930, from cirrhosis of the liver—but not before his peers in the industry awarded him the Perkin Medal for his achievements in industrial chemistry. At his death, the company he created was doing $15 million in annual sales and employing approximately two thousand people.

IMPACT

Dow's work to produce bromine and later chlorine in large quantities for commercial sale, and his concurrent effort to establish the business that would carry out his revolutionary ideas for the manufacture of products generated from chemical processes, led to the establishment of one of America's largest and most influential chemical products companies. Dow Chemical supplied products used for cleaning, for manufacture of pharmaceuticals, for agricultural products, and for military weaponry. Research at Dow Chemical led to the development of dozens of products that materially improved the living standard of American citizens. Dow's insistence that his company continually investigate new products or new uses for existing ones set a standard for others involved in manufacturing products made from chemicals. Dow's practice of involving faculty and students from the Case School in research and product testing set a precedent for university-industry partnerships that became a standard adopted across the nation during the twentieth century.

Nevertheless, even in Dow's time the company became involved in manufacturing chemical products that would have an adverse impact on the environment. To many in the United States, Dow Chemical's role in manufacturing napalm, a powder mixed with gasoline and used in a "scorched earth" bombing campaign during the Vietnam War, seemed a natural outgrowth of Dow's complicity in producing poison gases in 1917-1918. Increasingly, the company came to be seen as a greedy international firm intent on making money regardless of the impact its products had on the environment or individuals. These unfortunate judgments marred the otherwise remarkable record of a company founded by a man who believed in the power of chemistry to make life better for his fellow citizens.

—*Laurence W. Mazzeno*

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See also: Wallace Hume Carothers; Michael Faraday; Charles Martin Hall; Stephanie Kwolek; Roy J. Plunkett.

CHARLES STARK DRAPER

American aeronautical engineer

Draper is often referred to as the "father of inertial navigation." His work with gyroscopes led to the development of the guidance computer for NASA's Apollo program and improved gun sights for antiaircraft weapons.

Born: October 2, 1901; Windsor, Missouri
Died: July 25, 1987; Cambridge, Massachusetts
Primary fields: Aeronautics and aerospace technology; military technology and weaponry
Primary inventions: Inertial navigation systems; Mark 14 gun sight

EARLY LIFE

Charles Stark Draper was born to Arthur and Martha Draper in Windsor, Missouri. His father was a dentist and his mother was a schoolteacher. In 1917, Draper enrolled in the University of Missouri, where he planned to study medicine. In 1919, he transferred to Stanford University in California, graduating in 1922 with a bachelor's degree in psychology. He then attended Herald's Radio College in order to work as a ship radio operator. After finishing his training, Draper took a road trip cross-country with a friend who was attending Harvard. On their way to Boston, they drove through Cambridge. Draper was taken with the town, especially the Massachusetts Institute of Technology (MIT). That day, he enrolled in MIT's electrochemical program.

In 1926, Draper received his bachelor's degree in electrochemical engineering. He stayed at MIT, studying mathematics, physics, chemistry, and aeronautics. Draper was given a nondepartmental master of science degree in 1928. He became an aeronautic engineering research assistant at MIT the following year. He continued taking a wide range of courses while working on his Ph.D. and became renowned for having the most credits of any MIT graduate student without a doctorate. MIT eventually pressured Draper to complete his degree. He finally finished his doctorate in 1938. He married Ivy Willard later that year.

LIFE'S WORK

Draper became a professor at MIT in 1939. The college also put him in charge of its Instrumentation Laboratory, which now bears his name. His first project after taking over the MIT lab was to improve navigation by developing a new gyroscopic rate-of-turn indicator. The Sperry Gyroscope Company funded Draper's research. Simply put, a gyroscope is a spinning wheel device that aids stability. Small gyroscopes, which resemble complex toy tops, are sold at educational and toy stores. Gyroscopes measure angular velocity—the amount of angular displacement (the difference in angle of the radius of the wheel over a time interval) divided by the total elapsed time. Angular velocity is measured in radians per second. Gyroscopes measure angular velocity in an inertial reference frame, a set of coordinates in space that is not accelerating. By knowing the initial orientation within the reference frame, and calculating in the angular velocity, it is possible to always know the system's current orientation.

Draper was successful in creating more sensitive gyroscopic instruments, but they did not have practical applications until the beginning of World War II. Draper used his improved rate-of-turn indicator to develop the Mark 14 gun sight, which made antiaircraft fire from ships possible. The USS *South Dakota* was the first to use the device. In 1942, the ship successfully shot down thirty-two Japanese aircraft during the Battle of Santa Cruz. The Mark 14 gun sight was able to semiautomatically correct for wind, range, and ballistics using the ship's deck as the inertial reference frame. The gun sight became popular with Allied forces; more than eighty-five thousand of the devices were installed on American and British vessels. Draper also worked on a gun sight for airplanes. Later models gave American pilots an advantage during the Korean War.

Inertial Navigation Systems

In the years following World War II, the scientific debate over the plausibility of building an inertial navigation system (INS) increased. Charles Stark Draper and his supporters believed it was possible. Others, such as physicist George Gamow, disagreed. A member of the Air Force Scientific Advisory Board, Gamow felt that the military was wasting money working on an INS. He was convinced that the "problem of the vertical" could not be solved.

The problem of the vertical came from Albert Einstein's "black box" argument: An observer inside this box would not be able to tell the difference between gravity and linear acceleration. This argument presented problems for Draper and his colleagues working on creating an INS, or black-box navigation. The navigation system on an airplane would need to be able to identify the true vertical. For example, when navigating with two accelerometers, they are oriented "local vertical," meaning horizontally at right angles to the local direction of gravity. When the black box accelerates, a plum bob would not give a correct indication of true vertical. Another problem could arise if direction of travel was unknown. In that case, it would be impossible to know if the gyroscopes were even being held horizontally.

Mathematician Max Schuler believed that an INS was possible in theory and began working on the calculations dealing with the effect of a vessel's acceleration on the onboard gyrocompass. Schuler was trying to find a way to minimize that effect. His work, eventually published in 1923, was central to solving the problem of the vertical. On a ship traveling the surface of the earth, it is impossible to determine the vertical using a plum bob if the ship accelerates. Schuler's theoretical solution was to increase the length of string holding the plum bob weight so that it puts the mass at the center of the earth. In this case, the string would indicate the vertical, no matter how the ship moved or accelerated. An actual version could not be constructed, but Schuler argued that the effect could be achieved with a gyroscope system. The gyroscope could be set to the same oscillation period, eighty-four minutes, as the earth-radius pendulum.

Scientists working on the problem of the vertical and INS were confident that Schuler's idea would work. The easiest way was to construct an earth-radius pendulum using two accelerometers at right angles, stabilized by gyroscopes. Draper and his colleagues thought this was a viable solution to the problem of the vertical.

In the late 1940's, Draper finally put an end to the debate over black-box navigation. He and Gamow were both members of the Scientific Advisory Board; Draper set up a conference for those working on the INS to discuss the status of their research. Though Gamow was invited, he did not attend the meeting. His absence was perceived as admitting that he was wrong about the vertical problem. Within a few years, Draper had successfully created an inertial navigation system.

During the years following the end of World War II, Draper began working on an inertial navigation system (INS), which is used to determine the current position of a ship or plane based on the initial location and acceleration. Draper and his colleagues at MIT worked with the Air Force Armament Lab on the guidance system. Draper's INS would be unaffected by enemy countermeasures or bad weather. He based his guidance system on the principles behind the Mark 14 gun sight, which used a gyroscope with only one direction of freedom; the gyroscope floated inside a viscous liquid. For the INS, Draper created a floating gyroscope accelerometer with three directions of freedom that measured position, velocity, and acceleration. His new accelerometer connected to an airplane's instruments measuring direction and altitude, forming an inertial guidance system.

There was much debate within the scientific community about whether an INS would actually work. The most vocal critic was American physicist George Gamow. To prove his system worked, Draper set up a test flight in 1953. However, since it was a military program, it was not made public until 1957. Draper, seven other MIT engineers, and an Air Force crew flew from Bedford, Massachusetts, to Los Angeles. During the twelve-hour flight, no one touched the plane's controls until they were ten miles from Los Angeles, to prepare for landing. The plane had successfully adjusted its altitude and speed on its own as it flew across country.

Draper also worked on designing a system for U.S. Navy ships and submarines. Draper's Ships Inertial Navigation System (SINS) was not affected by the fact that over the course of months a ship's gyroscopes tend to need recalibrating. Navy leaders funded Draper's research, hoping to use it in nuclear submarines. They also asked him to develop a navigation system for ballistic missiles that would work in coordination with SINS. The systems were first installed in ships, planes, and submarines in 1956 and in ballistic missiles four years later.

In 1961, Draper and the other engineers at the instrumentation laboratory began working on guidance and control systems for the Apollo program of the National Aeronautics and Space Administration (NASA). Robert Seamans, deputy administrator of NASA, had taken the Weapons System Engineering course that Draper set up to educate civilian and military personnel about his INS. Seamans gave Draper the Apollo contract. It was Draper's invention that successfully guided astronauts Neil Armstrong, Buzz Aldrin, and Michael Collins to the Moon in 1969 and brought them back safely.

During the late 1960's, antiwar protests occurred often at MIT, mainly because of the lab's strong military ties. MIT faculty and administration debated the effects the military funding was having on the college. In 1973, the lab was moved off MIT's campus and renamed the Charles Stark Draper Laboratory.

Charles Draper died on July 25, 1987, in Cambridge. He and his wife had four children: James, Martha, Michael, and John. Draper was eighty-five.

IMPACT

Draper had a large impact on military and civilian life. The gun sight that he invented in the 1940's gave U.S. Navy ships an advantage against enemy aircraft. Draper's design also created a new field of research: aided tracking fire control. The Draper laboratory is among many groups working to improve the military's "Dismounted Soldier" project, developing ways to fire missiles, drop bombs, and deliver supplies without putting pilots and flight crews at risk. The military's Joint Precision Airdrop System (JPADS), which uses guided parachutes in resupply missions, was first used in combat in Afghanistan in 2006. The laboratory is also working on low-cost guidance systems for ballistic missiles. With these systems, the Navy would be able to fire long-range missiles in support of ground troops. The project has already increased the range and accuracy of two types of missiles used by the Navy.

Draper's inertial guidance system was being installed on commercial airplanes by 1970. Draper also played a key role in the Apollo missions to the Moon. Newer versions of his system have been built for the space shuttle and International Space Station (ISS). When the ISS had problems with its onboard Russian computers in 2007, guidance control was maintained by Draper's INS until the computers could be repaired. Future NASA missions, both manned and unmanned, will no doubt be equipped with versions of Draper's inertial navigation system.

—*Jennifer L. Campbell*

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See also: Harold E. Edgerton; Albert Einstein; Léon Foucault; Elmer Ambrose Sperry.

CHARLES RICHARD DREW

American physician and medical researcher

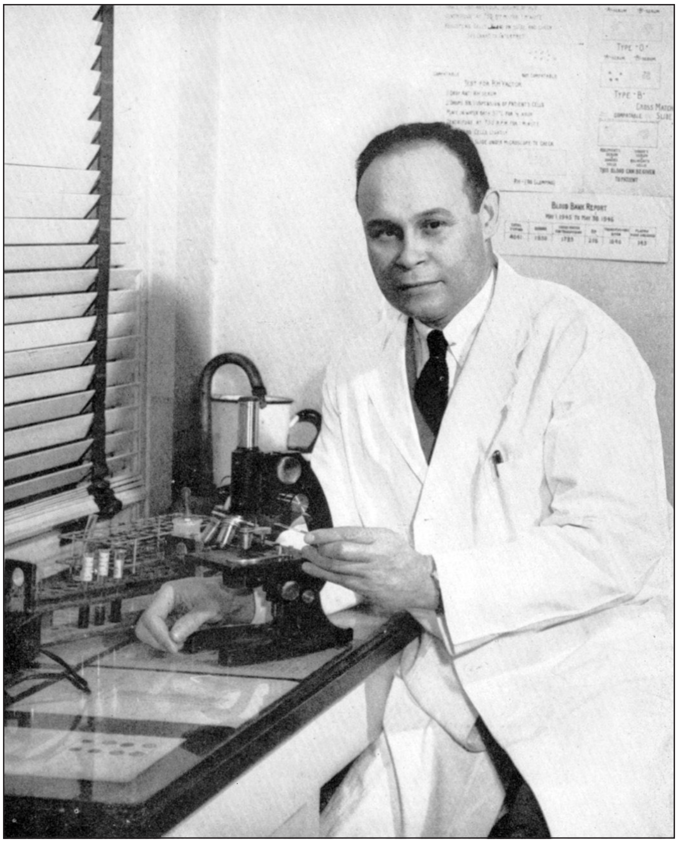
Drew developed a system of collecting and storing blood plasma in what is known as a blood bank, which was utilized for Allied fighting men in World War II. Whereas previously blood could be preserved for only about seven days, Drew's method made it possible to store the plasma for much longer periods of time.

Born: June 3, 1904; Washington, D.C.
Died: April 1, 1950; near Burlington, North Carolina
Primary field: Medicine and medical technology
Primary invention: Blood bank

EARLY LIFE

Charles Richard Drew was the first of five children born to Richard (a carpet layer) and Nora (a teacher) Drew. He was an exceptional student and athlete, earning four varsity letters in high school. Voted best overall athlete in both his junior and senior years, he graduated from Dunbar High School in 1922 with honors and a partial athletic scholarship to play football at Amherst College. As the scholarship paid only some of his expenses, he took a part-time job as a waiter. Between his athletic activities and his job, his grades suffered during his first two years of college but improved by his junior year. His athletic career continued to be outstanding. He was an all-American halfback and captain of the track team.

Upon graduation in 1926, Drew took a position at Morgan State University in Baltimore, Maryland. He wanted to become a doctor but was unable to pay for medical school at the time. He worked at Morgan, saved his money, and after two years resigned to enroll in the McGill University Medical School in Montreal, Canada. In 1933, he was awarded a medical degree and a master of surgery degree from McGill, where he had won first prize in physiological anatomy and two fellowships in medicine. From 1933 to 1935, he interned at the Royal Victoria Hospital and completed his residency at Montreal General Hospital. He returned to the United States to teach pathology at Howard University College of Medicine in Washington, D.C. In 1939, he married Minnie Lenore Robbins, with whom he had four children.



Charles Richard Drew. (Associated Publishers)

LIFE'S WORK

Drew's life work began in earnest after he earned his doctorate from Columbia University in 1940. He was a General Education Board fellow in surgery at Columbia from 1938 to 1940 and a resident in surgery at Presbyterian Hospital. His research on blood plasma and transfusions discussed methods for separating red blood cells from plasma to preserve them for later reconstitution and use. Conventional blood-preservation methods at the time focused on whole blood, which could be stored for only about seven days. Drew found that plasma could be stored much longer. In his two-hundred-page doctoral dissertation titled "Banked Blood: A Study in Blood Preservation," he showed that blood could be preserved longer if the red blood cells were separated from the plasma and frozen separately. When a blood transfusion was needed, the separated elements could be reconstituted.

World War II was under way in Europe, and doctors needed blood supplies for wounded soldiers and civilians. Aware of Drew's findings, one of Drew's former teachers, then living in England, requested that he send ten thousand glass containers of dried plasma to England to be used in transfusions. This required an all-out effort to collect blood at New York hospitals for export to England. Because the United States might also soon be drawn into the war and need a large blood supply, Drew devised a new mass-production technique to separate the blood components and stockpile them.

British scientists were using modified cream separators to separate plasma from red blood cells, a system far more productive than spinning off the red cells using test tubes and centrifuges or simply allowing the cells to separate and settle apart from the plasma over a period of several days. Drew ordered two of the modified cream separators from England and, with his associates, constructed similar machines to mass-produce clear plasma from the whole blood being collected by the American Red Cross and the National Research Council. This new system produced the volume of plasma likely to be needed when America went to war.

With war imminent, the American Red Cross named Drew director of its blood bank, and he was made assistant director of the National Research Council to manage blood collection for the American armed services in early 1941. Throughout the war, Drew's collection and preservation process was used; mobile blood banks were used at the front lines to treat wounded soldiers and stabilize them sufficiently to get them to hospitals.

One negative development occurred when the military ordered that all collected blood be separated by the race of the donor. Drew and other scientists and medical professionals tried unsuccessfully to convince the military that there was no difference between the blood of black and white people. They argued that men could die unnecessarily while waiting to receive the "right" blood, but they could not persuade the military to change the policy, which remained in force through the war.

In May, 1941, when Drew resigned as director of the American Red Cross, it was rumored that he left in protest over the segregated blood issue. Years later, however, his widow denied this rumor, saying that he returned to Howard University because he missed working as a teacher and surgeon. That same year, he was made head of Howard University's surgery department and chief surgeon at Freedman's Hospital. By 1944, he had become chief of staff at the hospital, a position he held until 1948.

Drew received numerous awards and prestigious ap-

THE BLOOD BANK

While Charles Richard Drew was a student at McGill University, he worked with visiting British professor Dr. John Beattie on his research in blood transfusions. It was understood that to avoid negative reactions in a blood transfusion, the donor and recipient blood types (A, B, AB, and O) have to match. Otherwise, the patient's immune system will attack the donated blood cells. At that time, whole blood was usually transfused, and therein was another problem: Whole blood was impossible to preserve for long periods of time, so a method was needed to preserve blood for transfusions so it would be available whenever needed.

Drew found that the red blood cells had a rapid deterioration rate. They are the blood components that carry hemoglobin, which combines with oxygen from the lungs and distributes the oxygen throughout the body. With the red blood cells removed, the liquid portion of blood, the plasma, could be stored practically indefinitely. Plasma, with no red blood cells (which contain the substance that determines blood type), could be used in transfusions without having to match donor and recipient blood types. This was particularly valuable in emergency cases. Drew transformed the test tube method of separating red cells from plasma into a mass-production technique.

Although blood plasma is not a substitute for whole blood in certain kinds of transfusions, it remains in the circulation for a much longer period than the previously used saline or glucose solutions, and it helps prevent or cure shock. In cases of burns, shock (without blood loss), or some cases of anemia in which the main concern is increasing the volume of circulating blood, plasma has been found to be highly valuable.

Using a dehydration process, Drew dried plasma for preservation and convenient transportation. To prepare it for transfusion, the plasma was simply reconstituted with distilled water just before it was to be used. In its reconstituted form, it stays fresh for about four hours. Plasma was found to be viable even a year after storage.

Drew's process of collecting, preserving, and using plasma was invaluable during the years of World War II. Because the demand for plasma was extremely high during the war years, Drew also pioneered the use of trucks equipped with refrigerators ("bloodmobiles") to carry the plasma to those who needed transfusions. Thanks to his work, hundreds of thousands of lives have been saved with blood plasma and its ability to stabilize injured people, regardless of blood type.

pointments for his exemplary career. Among them were honorary degrees from Virginia State College in 1945 and from his alma mater, Amherst College, in 1947. He held membership on the American Board of Surgery, the first African American to do so. In 1944, he was awarded the Spingarn Medal by the National Association for the Advancement of Colored People (NAACP) for his outstanding achievements.

On April 1, 1950, while driving through North Carolina with a small group of students and colleagues to the annual meeting of the John A. Andrews Clinical Association in Tuskeegee, Alabama, Drew fell asleep at the wheel, and the car struck a soft shoulder and overturned. His injuries were the most serious: a closed head wound, a chest crushed by the steering wheel, and severe injuries to his arms and legs. He was taken to Alamance County General Hospital in nearby Burlington, where, according to urban legend, he was refused treatment because of his race. In fact, he received immediate care but was too badly injured to survive.

IMPACT

Drew was a pioneer in blood collection and plasma processing. His experimentation turned biological research into mass-production methods that resulted in a new way to produce large quantities of transfusible blood. His work saved the lives of thousands of World War II servicemen and servicewomen and created a system of blood transfusion that saved lives in other wars and calamities. He devised a quantitative procedure for separating blood cells from plasma and preserving the components for longer periods of time than had previously been possible. His blood bank was a revolutionary advancement in modern medical practice, and the American Red Cross blood program today is a direct result of his groundbreaking work in mass-producing human plasma.

—Jane L. Ball

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Love, Spencie. *One Blood: The Death and Resurrection of Charles R. Drew*. Chapel Hill: University of North Carolina Press, 1997. An extensively researched, insightful discussion of how rumors and opinions affect history, with focus on how Drew died, medical care and race relations in America at the time of his death, and some of the myths surrounding his death.

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See also: Helen M. Free; Willem Johan Kolff; Rosalyn Yalow.

RICHARD G. DREW

American engineer

Drew, an engineer at the Minnesota Mining and Manufacturing Company (3M), invented transparent adhesive tape in 1930. His work evolved into a line of pressure-sensitive tape products numbering over nine hundred and generating $24.5 billion in sales by 2007.

Born: June 22, 1899; St. Paul, Minnesota
Died: December 14, 1980; Santa Barbara, California
Also known as: Richard Gurley Drew (full name)
Primary field: Household products
Primary inventions: Scotch tape; masking tape

EARLY LIFE

Richard Gurley Drew was born on June 22, 1899, in St. Paul, Minnesota. After high school, Drew attended the University of Minnesota to study engineering. For three semesters, he studied engineering during the day and paid his college expenses by playing banjo in various Twin City dance orchestras at night.

Drew found this schedule grueling, however, and quit the university. He continued to play the banjo and spent his afternoons on a correspondence course in machine design. He was twenty-two years old and had not yet found his career path, but that would change when Minnesota Mining and Manufacturing Company (3M) decided to increase the size of its research laboratory in 1921.

William Vievering, 3M's first quality-assurance expert, ran a blind advertisement in a St. Paul newspaper looking for an assistant in the research lab. Drew was ready for a change and wrote back, "I realize that my services would not be worth much until a certain amount of practical experience is gained, and I would be glad to start with any salary you see fit to give." He got a job as a lab technician and worked for his entire career at the company.

LIFE'S WORK

Drew's life work was with 3M. From 1921 until he retired in 1962, he continued to work on new products, earning thirty U.S. patents as a result of his inventive efforts. His first major invention was an improved masking tape for auto body workers, patented in 1925. The tape made possible the two-tone paint schemes popular at the time because it stayed on the car through the paint process but came off after the paint dried without removing any of the paint when the tape was peeled away.

In 1930, Drew invented the product that revolutionized the tape industry. It was the first waterproof, see-through, pressure-sensitive tape that also acted as a barrier to moisture. The product was such a resounding success that even though the Great Depression was soon upon the country, 3M continued to thrive and did not have to lay off workers. Called Scotch tape, the product got its name when an auto painter became frustrated with Drew's sample masking tape (with adhesive only on the outer edges, not the middle), which fell off the car. He exclaimed to Drew, "Take this tape back to those Scotch bosses of yours and tell them to put more adhesive on it!" In his pejorative statement, "Scotch" meant "cheap." The pressure-sensitive tape that Drew later developed was highly successful because it had many uses around the house, from repairing torn pages in books to fixing broken toys and ripped curtains.

Propelled in large part by Drew's approach to inventing, the company culture of 3M was changed in the 1930's. Drew and two other men who were hired at the same time in 1921, Richard Carlton and Francis Okie, formed what could be called a "dream team" at 3M. They

SCOTCH TAPE

When Richard G. Drew first began work at the Minnesota Mining and Manufacturing Company (3M) in the early 1920's, the company's major product was sandpaper. As part of product testing 3M's Wetordry sandpaper, Drew visited a local body shop, which needed sandpaper to prepare metal surfaces prior to painting.

Drew noticed the problems that the painters were having with the popular two-tone paint jobs. They were using a gummed tape to make the sharp edge between the colors, and when they removed the tape, some of the paint came with it. Drew was inspired to develop a tape that would meet the demands of the auto body industry.

3M already had some of the technology in place to produce a masking tape that would do the job because the sandpaper it manufactured required an adhesive compound to attach the "sand" to the "paper." Drew designed a sample masking tape and took it to the auto body painters for testing. To make the two-inch-wide tape more affordable, he applied adhesive only to the edges. When a car painter used the test tape, it fell off and, as the story goes, the painter told Drew to return the tape to his "Scotch bosses." The name "Scotch" was memorialized when Drew later designed the first line of successful transparent adhesive tape that he called Scotch tape. Today, even the tape dispensers are clad in plaid (suggesting a kilt).

The first tape that Drew invented was the result of two years' effort experimenting with vegetable oils, various resins, linseed, and glue glycerin. The final version was made in 1925 from cabinetmaker's glue; the tape was kept sticky with glycerin and used crepe paper for backing. This new Scotch Brand Masking Tape stuck to the car body but came off without pulling the paint with it.

Drew's invention set the stage for further development of a wide variety of tapes, all under the Scotch trademark. The one most widely known to the public was invented in 1930 under the name Scotch Brand Cellulose Tape. The name was later changed to the now famous Scotch Brand Transparent Tape.

The impetus for the transparent tape came in 1929, when the Flaxlinum Company, a St. Paul insulation firm, was contracted to insulate railroad refrigeration cars. The company needed a moisture-proof tape with which to wrap the insulation bats. The Scotch Brand Masking Tape did not work, however. By the time Drew and his assistants solved the problem a year later, the Flaxlinum Company was no longer interested, but there were many other potential customers such as bakers, meatpackers, and grocers. Pressure-sensitive tape soon became a ubiquitous feature of the manufacturing world.

were the early architects of innovation, independent thinkers who liked to tinker with ideas.

Over the years, Drew served as a mentor to many young engineers and inventors at the company. One of those was Paul Hansen, who worked as technical director at 3M. Hansen stated that working with Drew taught him many timeless lessons, which included these maxims: Anything worth doing is worth doing before it is perfected. Be a jack of all trades but a master of one. Put things in a nutshell. Be able to look at the broad picture and see the simple definition of the problem or task. It is easier to ask forgiveness than permission. Follow your instincts; your instincts are actually your total experience in practice. Don't keep blinders on all the time. It is good to have goals, but look around for opportunities at the same time. Most people are not stubborn enough; too many people give up at the first sign of failure. The reward for persistence is internal. People are generally recognized for the products of the work. The satisfaction also has to come from the effort that goes into making the success a reality.

In 1943, Drew established and became director of the Products Fabrication Laboratory (later the 3M Corporate Research Laboratory). Over the next twenty years, the lab worked on products ranging from improved reflective sheeting for traffic signs to breathable surgical tapes. The lab also performed experiments that led to the development of the Post-it note forty years later.

In 1978, Drew was inducted into the Minnesota Inventors Hall of Fame, and in 2007 his influence and achievements were again recognized as the National Inventors Hall of Fame inducted him as a member. Drew died at the age of eighty-one in 1980. His ever-handy products continue to live on.

IMPACT

Drew's place in history was firmly established by his invention of transparent adhesive tape. (More than 4.1 million miles of Scotch tape are sold every year, enough to circle Earth 165 times.) Still, Drew's greatest impact arguably could be the role he played in changing corporate culture as it relates to the inventive spirit.

One of Drew's first assignments with 3M was to improve the company's line of sandpaper. It was during this time that Drew became interested in making a tape that would mask off parts of a car so that different colors of paints could be applied. It was a frustrating process trying to get the right combination of materials for the tape, especially for its backing. After some time, William L. McKnight, president of 3M, told Drew to quit his personal project and return to the sandpaper project.

Drew, however, continued to work on the tape project, even going so far as writing multiple purchase orders for $99. (Everything over $100 had to be approved by management.) Drew eventually achieved success despite management's directives, and McKnight realized that the creative spirit should be encouraged, leading to what today is known in business as "bootlegging," or the 15 percent rule. Under this policy, employees are encouraged to use 15 percent of their working hours on projects of their own choosing. This policy helped 3M grow into one of the most innovative and successful companies in the world, and many other corporations followed suit, establishing similar work atmospheres for research and development.

—*Tom A. Hull*

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See also: Patsy O'Connell Sherman; Lewis Waterman.

JOHN BOYD DUNLOP

Scottish veterinarian

Dunlop developed many aspects of the pneumatic tire at exactly the right historical moment: Cycling was in its infancy, and the age of the motorcar was just around the corner. His inventions ensured the success, safety, and popularity of bicycles, automobiles, and other vehicles.

Born: February 5, 1840; Dreghorn, Ayrshire, Scotland
Died: October 23, 1921; Dublin, Ireland
Primary field: Automotive technology
Primary invention: Pneumatic rubber tire

EARLY LIFE

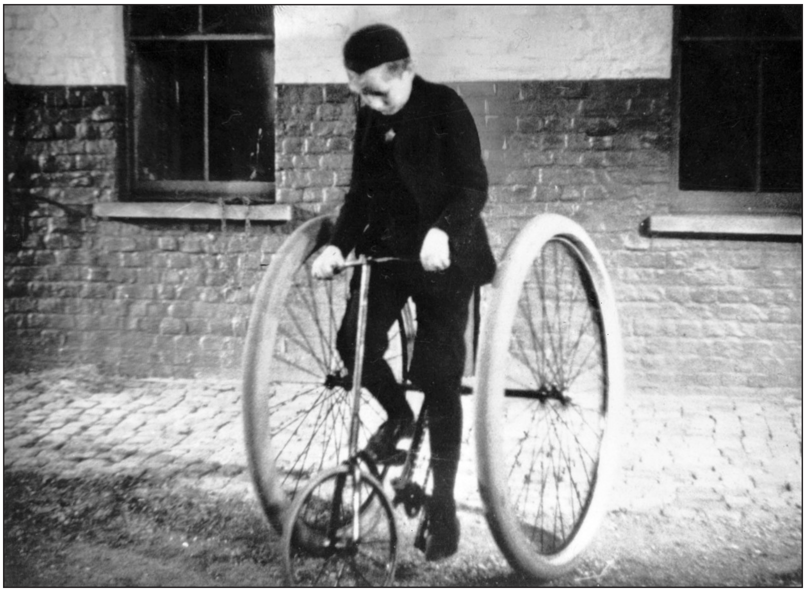
John Boyd Dunlop (DUHN-lop) was born into a farming family on February 5, 1840, in Dreghorn, Ayrshire, Scotland, the son of John Dunlop, a tenant farmer, and his wife, Agnes (née Boyd). As a young boy, he attended the local parish school and so excelled that even at an early age the schoolmaster had him teach arithmetic to the younger pupils. At some point, however, he was told that he was born two months earlier than expected. This apparently trivial point appears to have seriously disturbed Dunlop: He believed that it must have affected his health, and for much of his life he tended to avoid travel and other exertions. Indeed, he was considered somewhat too fragile as a boy to work on the farm and had to complete his schooling in Edinburgh. Having spent much of his childhood on the family farm, he developed a love of animals that undoubtedly influenced his decision to pursue a career in veterinary medicine.

He attended the Royal (Dick) Veterinary College in Edinburgh (now part of the University of Edinburgh) and was an excellent student, completing his studies in April, 1859, at the age of nineteen. After earning his diploma, along with an honorary fellowship of the Royal Veterinary Society of Edinburgh, he worked as a veterinarian in the city for several years before moving to northern Ireland in 1867 and establishing a very successful practice in Belfast. He married Margaret Stevenson, a farmer's daughter, in 1871, with whom he had a son, John (Johnnie), and a daughter, Jean.

LIFE'S WORK

Dunlop became well known in Belfast as a kind man and an excellent vet, a reputation that contributed to the success and growth of his practice. Within twenty years, his was one of the largest practices in Ireland, so large that he had to employ twelve men just to shoe horses. (Veterinarians at this time were essentially horse doctors and were almost indispensable, as horses were in such widespread use for personal and commercial transportation.) Dunlop had to cover a large area in his work and would have endured many uncomfortable rides, which, for a man of a delicate constitution, would have made him only too well aware of the bumpy nature of the city's streets.

His concern for the welfare of animals led him to attempt to ease the discomfort of horses that had to strain to haul heavy loads. The family doctor, Sir John Fagan, who was also a client of the veterinary practice, mentioned that he often attempted to improve his patients' comfort by having them lie on air-filled cushions, an idea that Dunlop attempted to apply to horse collars. Fagan



In 1887, John Boyd Dunlop rebuilt the tires of a tricycle for his son, Johnnie (pictured). The following year, Dunlop received a patent for his pneumatic tires, and the modern tire industry was soon established. (Roger Viollet/Getty Images) also suggested that ten-year-old Johnnie take up cycling as exercise.

The pedal bicycle had itself been invented only a few decades earlier by Kirkpatrick MacMillan in 1839, but its wheels were bare metal, giving no comfort over the jolts and vibrations of the roadways. Solid rubber tires were introduced after Charles Goodyear's improvement of the vulcanization process (patented in 1844) that made rubber sufficiently durable for such use, but they gave only moderately better comfort. The bicycle itself underwent many developments, culminating in the invention of the "safety cycle" by John Kemp Starley in 1885. One of the most significant and fundamental changes to the bicycle, and one that would revolutionize its use, was made by Dunlop just three years later.

Johnnie complained of the jarring he experienced in riding over the bumps of Belfast's cobbled streets, prompting his father to set himself to make cycling more enjoyable for his son. He realized that air would cushion the ride of a cyclist, just as it cushioned his horses' collars and Fagan's patients: He made the crucial mental leap to see that a hollow tube filled with air, attached to the rim of each wheel, would provide the means to achieve this. Dunlop's first experiments used a solid wooden wheel, to which he attached the inflated rubber tube inside a rubberized canvas cover nailed to the wheel. By comparing the bouncing and rolling properties of this wheel with one shod in solid tires, he not surprisingly found that the cushioned tires performed better. Next, Dunlop applied his principle to the rear wheels of his son's tricycle. He improved the construction of the covered air tubes, attached them around wooden wheel rims, and even included a primitive valve for inflation of the tire. A trial of the modified tricycle in February, 1888, conducted secretly at night, immediately established its improved comfort and speed. These successes led Dunlop to demonstrate his technology to local businessmen, and he applied for a patent for his pneumatic tires in July, 1888.

Many more tests were made, culminating in Dunlop designing and purchasing tires from a Scottish company that were fitted to locally built cycles. These were put on sale, complete with pneumatic tires. A local racing cyclist, William Hume, also ordered a machine equipped with the new tires, and when in May, 1889, Hume defeated many superior riders who raced with solid rubber tires, the future of the pneumatic tire seemed secured. Later that year, Dunlop went into business with the entrepreneur William Harvey Du Cros, whose sons had been among the riders Hume de-

Pneumatic Tires

The tires of any automobile, bicycle, or other wheeled vehicle are generally the only part of that vehicle that is in constant contact with the surface of the roadway. As such, they are a crucial part of the vehicle's design, being integral to any consideration of its potential speed and maneuverability, the comfort of its ride, and its safety. The pneumatic tire is beneficial in all these aspects when compared with solid tires—and certainly when compared with bare wheel rims.

Modern pneumatic tires follow a design that is not much different from John Boyd Dunlop's. They consist of a continuous air-filled rubber cushion that forms a ring around the rim of a wheel. This is surrounded by outer protective layers that help maintain the integrity of the crucial inner tube. Rubber and rubberized fabric are still the basic components, and steel wire is still used to hold the tire to the rim. Chemicals are added to the rubber to improve its resistance to wear, heat, and aging. Dunlop's original tires were made from natural rubber, which is slightly air-permeable and hence suffered from very slow deflation, just like a balloon. The inner tubes of modern tires use synthetic butyl rubber, which is much more impermeable.

Robert William Thomson's invention of the pneumatic tire in 1846 was far ahead of its time. His design was rather elaborate, and, although it worked well, was too costly and impractical. Nevertheless, his experiments with horse-drawn wagons did establish significant improvements in traction on a variety of surfaces. Had there been sufficient demand for his innovation, history would have remembered and celebrated Thomson, and not Dunlop, as the true inventor of the pneumatic tire.

Dunlop, on the other hand, was also lucky. In 1888, he independently "reinvented" the pneumatic tire at a crucial point in the history and development of transportation. Cycling was just beginning to take off, and the internal combustion engine was soon to be invented, giving birth to the motorcar. Equally important was the fact that the rubber industry and rubber technology were well established in Dunlop's time. The pneumatic tire took cycling from the realm of racing, where only the most determined sportsmen would tolerate such excessive vibrations, and turned it into a highly popular pastime that could be enjoyed by all. Moreover, in practical terms, the motorcar would have been impossible without pneumatic tires. All of these factors contributed to the demand for, and success of, Dunlop's pneumatic tires.

feated, and the two men launched the Pneumatic Tyre and Booth's Cycle Agency.

After retiring from practice in 1892, Dunlop remained active in the tire business. Du Cros, meanwhile, helped steer the company through many troubles, the principal of which was the revelation that Dunlop's patent was invalid: His fellow Scot, Robert William Thomson, had already patented the pneumatic tire in 1846. However, Dunlop and the firm held auxiliary patents, notably for the non-return valve, wheel rims, and methods of attaching the tire to the rim. The company survived much turmoil and litigation and would ultimately become the Dunlop Rubber Company, an international group that by 1954 comprised over 130 companies manufacturing a broad range of rubber goods, sports and cycling equipment, and, of course, tires.

Dunlop lived quietly in Ballsbridge, near Dublin, in his retirement. Despite his tendency to hypochondria, he enjoyed good health all his life and lived until the age of eighty-one. He had no serious illness until late 1921 when, suddenly and unexpectedly, he died following a slight chill on October 23. Dunlop had worked on a history of the pneumatic tire over the last few years of his life; the book was published posthumously by his daughter, Jean McClintock.

IMPACT

Dunlop's "reinvention" of the pneumatic tire revolutionized virtually all of land transportation. It is hard to think of riding in any road vehicle without the cushioning that tires provide. It is truly remarkable to realize that all of Dunlop's original experiments, and the technological advances that they brought, were achieved by a man who was neither a cyclist nor an engineer, but a vet, working only with his own hands and with the relatively simple tools and materials available to him at home and at his business.

Despite having no valid patent, Dunlop managed to bring his tires to the world, and they are now as ubiquitous as the bicycle and the automobile: Modern life is almost unimaginable without them. He made little profit from his invention, yet his name is remembered through the quirk of fate that he was—historically—in the right place at the right time. Nevertheless, his unique circumstances and his critical realization of the potential applications of pneumatics justify his place in history.

Dunlop's tires changed the world in many other unexpected ways as well. Ironically, they had a significant effect upon the veterinary profession. When the popularity of cycling and the automobile rocketed, with a corresponding drop in horse riding, "horse doctors" were forced to expand their horizons. They began treating pets and other types of animals, becoming much more like the veterinarians that are familiar today.

—Thomas D. McGrath

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; Henry Ford; Charles Goodyear; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; André and Édouard Michelin; Ransom Eli Olds; Nikolaus August Otto; Stanford Ovshinsky; Sylvester Roper; Ignaz Schwinn; Felix Wankel; Alexander Winton.

GEORGE EASTMAN

American businessman

Eastman invented roll film, making it possible for photographs to be taken more speedily without using breakable glass plates and hazardous chemicals. His invention allowed ordinary people to indulge in photography and opened the way for the rise of the motion-picture industry.

Born: July 12, 1854; Waterville, New York
Died: March 14, 1932; Rochester, New York
Primary field: Photography
Primary inventions: Roll film; Kodak camera

EARLY LIFE

George Eastman was born to George Washington Eastman and Maria Kilbourn. He had three older siblings, one of whom died in infancy. In 1865, his family moved to Rochester, New York, after his father established the Eastman Commercial College there. His father died in 1867, the college failed, and an older sister died in 1870. At the age of fourteen, Eastman quit high school to support his mother and sister as a messenger boy for an insurance company, earning three dollars per week. He eventually went to a different insurance company, where he made five dollars per week and was soon in charge of filing and writing policies. He was ambitious and bright, studying accounting at night, hoping to get a better-paying job. By 1874, he was working at a bank and earning fifteen dollars per week.

George Eastman. (©Smithsonian Institution)

At age twenty-four, he developed an interest in photography when he planned a vacation trip to Santo Domingo and it was suggested that he make a photographic record of his trip. He was irked to find how complicated that would be: The paraphernalia required to take photographs was very complicated. He needed not only a huge camera that required a heavy tripod to support it but also chemicals, tanks, a jug of water, glass plates, and a tent in which to make and apply the emulsions for the glass plates and in which to develop the exposed plates before they dried. In addition, he had to take lessons, at a cost of five dollars, to learn how to use all the gear for the picture taking. He did not go to Santo Domingo, but he continued to be fascinated with photography. Even as he continued working in the bank, he began what would become his life's work—finding new and simpler ways to make photographs.

LIFE'S WORK

About 1878, Eastman was inspired to find a way to eliminate much of the gear needed to take photographs. He probed journals dealing with photography and learned of a British emulsion process that kept the treated glass plates sensitive enough to take pictures even after the emulsion dried. He experimented with gelatin emulsions of his own design based on British formulas, working at night in his mother's kitchen after he had put in a day's work at the bank. It took him three years, but he finally produced a formula that worked. By 1880, he developed and patented a machine that would prepare the plates in greater numbers than previously possible. He decided to start his own company, the Eastman Dry Plate and Film Company, to make dry plates to sell to photographers.

On a leased third floor of a building in Rochester, he started making his dry plates. As the business grew, he saw the need for a product that would serve both professional photographers and amateurs. To make photography more convenient and accessible, Eastman worked to find a component to produce the photographic images that was lighter and more flexible than the bulky and breakable glass plates. After some experimentation, he found that an emulsion-coated paper on a roll could be used in cameras instead of glass plates. The paper roll film was successful even though the quality of the pictures taken with the film was not very satisfactory because the grain of the paper showed on the developed pictures. Eastman continued to experiment, using layers of gelatins that ultimately allowed the photographic image to be recorded on one of the gelatin layers instead of on the paper. This gelatinous flexible film eventually evolved into the familiar roll film.

Shortly thereafter, Eastman, along with associate William Hall Walker, designed and began the manufacture of a smaller, lighter-weight camera that could use the roll film. The result was the first Kodak camera, initially called the "roll holder breast camera." People who bought and used the camera got their pictures developed and printed by sending the entire camera back to the Eastman Company along with a $10 processing fee; they received back their printed pictures and their camera reloaded with a new 100-exposure roll of film, ready to use again.

By 1900, Eastman was interested in further increasing the burgeoning interest in photography. To make it a hobby for the masses, he introduced a camera costing one dollar, the Brownie, which he ostensibly intended for children. His earlier camera cost around $15 and was therefore out of the reach of many ordinary people. By 1901, the Brownie's price had dropped to 25 cents. Owners no longer had to send the camera to the manufacturer for processing; they bought and loaded the film, took the pictures, and needed to send only the film to the company for development and printing.

The Brownie was a fixed-focus lens box camera made of wood or metal (after 1930, plastic). Eastman's company also manufactured a folding camera that was compact and portable. Unlike other such cameras marketed around the country at the same time, the Brownie was both efficient and inexpensive; it was even capable of producing the popular postcard-size pictures.

Eastman's company became one of the most lucrative in the country. He stepped down from day-to-day management of the business by 1925 and became chairman of the board. He shifted his sights to philanthropy, becoming one of the most generous philanthropists of his

ROLL FILM

George Eastman's primary goal was to simplify the photographic process and reduce the amount of gear, time, and effort needed to take a picture. When he first set this goal, photographers had to go through a complicated process. A glass plate had to be coated with a liquid emulsion just moments before the picture was to be taken. Then, once the exposure was made, the picture had to be developed immediately. This required having a mobile darkroom to accommodate all the chemicals and paraphernalia right on the site where the pictures were to be taken.

Eastman, along with collaborators, first developed a dry, pre-coated plate that could be used in much the same way as the wet one, but with the convenience of being already prepared for exposure for the picture taking. However, in order to use a small camera that would not need a tripod, he worked to produce a dry, transparent, flexible film and a small camera to use it. The film he developed took pictures in black and white. He used paper as a light and flexible support for the needed emulsion. He coated the paper with layers of a soluble gelatin followed by layers of insoluble, light-sensitive gelatin.

The layers of gelatin had different roles to play in the making of a photograph. Some filtered light or controlled the chemical reactions that took place. Others, that made the actual image, contained silver-halide crystals, which underwent a photochemical reaction when exposed to light through the camera lens and thus captured the photographic image. Once the film was exposed, it was developed using chemicals that broke down the crystals into silver, enhancing the image. Another chemical was then used to halt the light sensitivity of the film and to set the negative image so that a picture could be printed.

This new flexible film, mounted on a spool, needed a new kind of camera, and Eastman invented the Kodak camera. A rectangular box with a fixed-focus lens, his camera could hold the spool of film and a take-up spool that allowed as many as one hundred exposures to be made without the need to unload or reload the camera.

These two inventions took photography out of the exclusive purview of professional photographers and introduced it to the masses as a way to record and save precious memories. They also opened up a new and lucrative business that made millionaires of Eastman and his associates. A direct by-product of Eastman's work was the development of the motion-picture industry, which owes much to Eastman's invention of transparent roll film.

time, an era that included such philanthropic giants as Andrew Carnegie and John D. Rockefeller. He donated more than $75 million over the years to various causes, including wage dividend benefits (profit-sharing) as incentives for his employees at the Eastman Kodak Company, setting up dental clinics in Rochester, and supporting the city's theater and symphony orchestra. Other recipients of his largesse were the University of Rochester, which he endowed with funds for a school of music and a school of dentistry; the Massachusetts Institute of Technology, which was given buildings; and Tuskegee and Hampton Institutes, which received some of the $30 million he earmarked just for educational institutions.

By 1930, Eastman had begun to experience poor health. He suffered from a degenerative spinal disorder, which may have been spinal stenosis (resulting from calcification in the vertebrae). His beloved mother had suffered the same kind of disease and was confined to a wheelchair during the final two years of her life. Having always been a very active person who traveled, often to Europe, and was involved in business and civic affairs, Eastman became increasingly depressed as he foresaw his coming incapacitation. Never married, though long involved in a platonic relationship with the wife of a business associate, he never really got over the loss of his mother when she died in 1907. He remembered how painful her last two years were and did not want the same end for himself. On March 14, 1932, he put his affairs in order and wrote a final note that read, "My work is done. Why wait?" and committed suicide with a pistol.

IMPACT

Eastman's inventions changed American photography, making photography something the masses could enjoy, where before only a few professionals could deal with its complexities. His roll film eliminated the fragile, cumbersome glass plates needed to catch the images in the bulky cameras of the time. Instead of relying on the slow, complicated process that produced one picture at a time using several procedures, Eastman's roll film sped up the process and allowed numerous images to be captured in fairly rapid succession. After roll film, he produced a camera to use the film, one that was smaller than its predecessors, easier to use, and certainly cheaper to buy. He said in his Kodak advertisements, "You press the button, we do the rest."

The Eastman Kodak Company made photography an easier business for professional photographers as well as an affordable, fun hobby for amateurs, and Eastman's work made him a millionaire. The wealth that he acquired because of his inventions was shared with others. He became involved in many philanthropic endeavors. Even before he became a millionaire, he began sharing his fortune with the employees of his company: He was one of the earliest businessmen to set up pension plans and insurance plans for workers. Once his fortune was made, he shared it in several different areas, particularly to the advantage of his hometown of Rochester, and to educational and medical institutions all over the country.

—Jane L. Ball

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Tedlow, Richard S. *Giants of Enterprise: Seven Business Innovators and the Empires They Built*. New York: HarperBusiness, 2001. The histories of seven business leaders, with chapters devoted to each. Eastman's chapter (about thirty pages long) tells how he accomplished his business success.

West, Nancy M. *Kodak and the Lens of Nostalgia*. Charlottesville: University of Virginia Press, 2000. Concerned mostly with the advertising strategies of the Kodak Company and how important they were to the company's success, as well as how they helped lure the American consumer to the hobby of photography. Many ads are reproduced; some of Eastman's inventions, the Brownie camera especially, are discussed.

See also: Harold E. Edgerton; Thomas Alva Edison; Auguste and Louis Lumiére.

JOHN PRESPER ECKERT

American electrical engineer

Eckert helped design and build the ENIAC, the world's first fully electronic, general-purpose computer. He also founded the first commercial computer company, the Eckert-Mauchly Computer Corporation, which designed the first commercial computer in the United States, the UNIVAC.

Born: April 9, 1919; Philadelphia, Pennsylvania
Died: June 3, 1995; Bryn Mawr, Pennsylvania
Also known as: John Adam Presper Eckert, Jr. (full name)
Primary fields: Computer science; electronics and electrical engineering
Primary inventions: Electronic Numerical Integrator and Computer (ENIAC); Binary Automatic Computer (BINAC)

EARLY LIFE

John Adam Presper "Pres" Eckert, Jr., was born in Philadelphia in 1919. The Eckert family was part of the economic and social elite. His father, John Eckert, Sr., was a wealthy real estate developer who arranged for a chauffeur to take his son to elementary school (William Penn Charter School). Pres liked to design and build things, especially electronics. He built a crystal radio set at age eight. At the age of twelve, he won first prize in a local science fair with a remote-controlled boat that floated in a large basin of water. It was steered with electromagnets under the basin. At age fifteen, he designed, and set off on the school stage, a remote-controlled bomb with a push-button box in the audience. He also designed a sound system for a nearby cemetery to mask the sound of the crematoriums so that mourners would not be disturbed. In high school, Eckert belonged to the downtown Engineer's Club of Philadelphia. He also spent afternoons in the laboratory of television inventor Philo T. Farnsworth, who lived in nearby Chestnut Hill.

Eckert enrolled in the University of Pennsylvania's Wharton School of Business. While his parents encouraged him to major in business, he soon transferred to the university's Moore School of Electrical Engineering and graduated in 1941. He then began graduate work at the Moore School and was offered a position. He applied for his first patent in 1940 (awarded in 1942) for what was essentially a motion-picture sound system.

LIFE'S WORK

By the time of Eckert's graduation, the Moore School had become a major source of technical and computational assistance for the U.S. Army Ordnance Department Ballistics Research Laboratory. The focus for the laboratory was the production of very complex ballistics firing tables, which provided trajectories for weapons. The first major joint project in the 1930's had been to build a differential analyzer (an electromechanical computer similar to one built by Vannevar Bush at Massachusetts Institute of Technology) to calculate ballistic trajectories.

At the Moore School, Eckert focused his research on radar (timing devices that measured the distance to targets). His work on radar involved the development of high-speed electronic circuits and a mercury delay line, both of which he used in later computer construction. He also made improvements to the speed and the precision of the school's differential analyzer.

Eckert took a position in 1941 as lab assistant for a summer school course on electronics offered by the U.S. Department of War through the Moore School. It was a ten-week crash course for people holding degrees in related fields to build a pool of expertise for war research. During the course, Eckert met Dr. John William Mauchly, chairman of the Physics Department at Ursinus College. Mauchly was enrolled in the course and took a teaching position at the Moore School that fall.

Mauchly came to the Moore School with ideas on the development of a computer. Initially, no one at the Moore School was very interested. By 1943, the Ballistics Research Laboratory had fallen behind in calculating ballistics tables because of the high demand during World War II. The Army asked the Moore School to build a machine to assist them. Eckert became the project's chief engineer and oversaw the design of individual circuits.

Construction of the Electronic Numerical Integrator and Computer (ENIAC) began in 1944. Although it was still considered in a test phase, the machine was used in the spring of 1945 to do calculations for ballistics projects and for the atomic bomb project at Los Alamos National Laboratory. In 1946, the ENIAC was disassembled and moved to the ballistics laboratory in Maryland. It became the first large-scale, electronic, digital computer in daily use.

While working on the ENIAC, Eckert and Mauchly developed the stored-program concept, which they incorporated into the design of their next computer, the Electronic Discrete Variable Automatic Computer (EDVAC). This concept involved storing data and programs together in memory so that the computer could be programmed without changing the electronics or rearranging plug boards. However, Eckert and Mauchly left the Moore School before the EDVAC was built.

Eckert wanted to pursue the commercial side of computers and partnered with Mauchly to found the Electronic Control Company. They received an order from the National Bureau of Standards (later the National Institute of Standards and Technology) to build the Universal Automatic Computer (UNIVAC) for the Census Bureau. While sorting out financing details on the UNIVAC, they built the Binary Automatic Computer (BINAC) for the Northrop Aircraft Company from 1947 to 1949. It was the first operational, electronic, stored-program computer in the United States. It was also the first machine that stored data on magnetic tape.

Eckert and Mauchly used their work on the BINAC to refine their plans for the UNIVAC. They also used the BINAC to demonstrate to potential customers and received orders for UNIVAC machines in advance of any construction on the first one for the Census Bureau. However, it was almost impossible to estimate production costs, and they ran into financial difficulties. In 1950, Eckert and Mauchly were forced to sell the company (which had become the Eckert-Mauchly Computer Corporation) to Remington Rand in order to avoid going bankrupt.

The first UNIVAC was delivered to the Census Bureau in 1951. It became only the second electronic computer produced for a commercial customer. The production of forty-five additional UNIVACs set up Remington Rand as the world's first large-scale computer company. The UNIVAC also showed the public just what a computer could do when it correctly predicted the winner of the 1952 U.S. presidential election based on samples of early returns—a surprising landslide victory for Dwight D. Eisenhower.

Eckert remained with Remington Rand and stayed with the company when it became Sperry Rand and finally Unisys. In 1989, he retired but continued to act as a consultant for

ENIAC

The Electronic Numerical Integrator and Computer, or ENIAC, was the most complex electronic equipment of any kind at the time it was built. It was programmable and used conditional (if-then) branching logic. Though the ENIAC was programmable, reprogramming the machine could take days. To give the computer new instructions, the operator had to change external wiring manually, similar to how a telephone operator used to rearrange plugs on a switchboard.

The ENIAC had been designed to calculate trajectories for weapons for the U.S. Army. Before the ENIAC, it took a person twenty hours to perform a trajectory calculation. The differential analyzer used at the Moore School before the ENIAC took thirty minutes. The ENIAC did the calculation in thirty seconds. The machine could execute up to five thousand additions per second.

The ENIAC took up eighteen hundred square feet with eighteen thousand vacuum tubes. It weighed thirty tons and consumed 174 kilowatts of power. The machine was made up of individual units arranged in a horseshoe shape along the outside walls of a large room. The units were accumulators, multipliers, a unit for division and square roots, a unit of three function tables to store values for use by the machine, a card reader for input, a card punch for output, and a programming unit.

The ENIAC stored decimal digits with a "ring counter" designed by John Presper Eckert that used ten "flip-flops" (0-9). A flip-flop consisted of a pair of vacuum tubes connected so that only one conducted electricity at a given time. The flip-flop was in a 1 (on) state when it was conducting and in a 0 (off) state when another was conducting. At a given time, only one flip-flop in the ring could be on. To add the number 2 to the number 3 already in the ring counter, the machine sent two pulses into the ring counter. This turned on the fifth flip-flop in the ring. Then, if six pulses were added, the "on" would travel all the way around the ring and produce a carry pulse that caused the next highest ring to advance one place as well as turn on the first flip-flop in this ring.

The ENIAC was much more reliable than early critics had predicted. Because of the known unreliability of vacuum tubes, Eckert chose to focus on careful circuit design for reliability. He employed a "worst case" design strategy. For example, if a resistor needed to be able to withstand at least 0.25 watt, he used resistors with ratings of 0.5 or above. He also used tubes that drew far less current than what they were rated for, and they lasted longer. Eckert used only a few basic types of circuits and made them easily accessible for servicing. He also designed vacuum tubes with an average lifetime of 2,500 hours once they reached a final operating temperature. However, they had a high failure rate during warm-up, so the ENIAC engineers did not turn off the machine. It was shut down on October 2, 1955.

the company. Between 1948 and 1966, Eckert took out patents on eighty-five inventions, almost all electronic in nature. He died of leukemia in Bryn Mawr, Pennsylvania, in 1995.

IMPACT

Pres Eckert, with John William Mauchly, invented the first general-purpose, electronic, digital computer. They also presented the first course in computing topics, founded the first commercial computer company, and designed the first commercial computer in the United States, which used the mercury delay-line memory developed by Eckert.

The ENIAC was the first electronic machine to solve complex numerical problems and had flexible enough programming that it could solve a variety of problems. It consistently and reliably solved numerical problems beyond human capacity and insoluble by any other means.

While World War II sparked the need for large numerical calculations and thus the need for computers, it was the perseverance and vision of Eckert and Mauchly that moved the computer out of university and government laboratories and into the commercial world. Although their attempts at commercialization were less than successful, Eckert and Mauchly built a foundation on which a viable computer industry developed in the United States. For many years, Remington Rand's product line was based on Eckert and Mauchly's basic designs.

—*Linda Eikmeier Endersby*

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See also: John Vincent Atanasoff; John Bardeen; John William Mauchly; George Stibitz.

HAROLD E. EDGERTON

American electrical engineer

Edgerton was an electrical engineer who pioneered the development of high-speed photography, employing and perfecting the electronic flash. He used the electronic flash to study motions as diverse as the splash of a milk drop and the flapping of the wings of a bat.

Born: April 6, 1903; Fremont, Nebraska
Died: January 4, 1990; Cambridge, Massachusetts
Also known as: Harold Eugene Edgerton (full name); Doc Edgerton
Primary field: Electronics and electrical engineering
Primary inventions: Electronic flash strobe light; high-speed photography

EARLY LIFE

Harold Eugene Edgerton was born on April 6, 1903, in Fremont, Nebraska, the eldest of three children to Frank Eugene Edgerton and Mary Nettie (Coe). His father was the high school principal and coached the football team. Edgerton's family moved several times. First, they moved to Washington, D.C., where his father served as a correspondent for the Lincoln, Nebraska, newspaper; then they moved to Lincoln, and finally to Aurora, Nebraska, where Edgerton attended high school. During that period, his uncle, Ralph Edgerton, a studio photographer, taught Edgerton the basics of photography. Edgerton bought his first camera when he was fourteen years old and set up a darkroom in his house so he could develop and process his own images.

As a child, Edgerton enjoyed taking apart mechanical devices to figure out how they worked and fixing those that were broken. While in high school, he worked for the Nebraska Power and Light Company. Although he was hired to perform janitorial and maintenance tasks in the office, many of the men who repaired the power lines were called into military service during World War I, and Edgerton was assigned to repair power lines. He described this job as challenging, because he had to solve different kinds of problems each day.

Edgerton decided to pursue a career in electrical engineering and entered the University of Nebraska, Lincoln, in 1921. He was awarded a bachelor of science degree in electrical engineering in 1925 and spent the next year working at General Electric in Schenectady, New York. In 1926, Edgerton began graduate studies in electrical engineering at the Massachusetts Institute of Technology (MIT), in Cambridge, Massachusetts.

LIFE'S WORK

Edgerton received his master's degree in electrical engineering from MIT in 1927. He was appointed an instructor in electrical engineering at the university, beginning a more than fifty-year association with the research institute. He also continued to work toward his Ph.D., investigating the effects of sudden changes, such as the power surge caused by a lightning strike on a power line, on the rotation of large electric motors. However, the motor rotated too fast for his eye to see the effects. Edgerton noticed that the device he was using to send power surges to the motor produced a flash of light accompanying each power surge. He realized that if he synchronized these light flashes with the rotation rate of the motor, its parts appeared to stand still.

In 1929, Edgerton asked Kenneth Beardsley, one of his graduate students, to use a pulsing mercury-arc lamp to examine motor rotation and to try to record the results photographically. Edgerton recognized that each light flash would expose an image, recording the motor's position in a photograph. By 1930, Edgerton was using a mercury arc that emitted sixty flashes per second, each having a duration of only $^1/_{100,000}$ second, to study the behavior of a motor as it began to rotate.

Edgerton and Beardsley were not the first people to combine a light flash with photography. The first flash photograph, made using a spark to expose the image, was made in 1851 by William Fox Talbot, shortly after photography was invented. At the time, photographs required very long exposures, so only stationary objects were suitable subjects. Talbot said that combining electric sparks with photography had the potential for obtaining photographs of moving objects. However, the spark photography technique was treated simply as a curiosity until Edgerton developed it as a serious research tool and a new art form.

Edgerton was awarded a doctor of science degree in electrical engineering in 1931, and his stroboscope was described in the May, 1931, issue of the research journal *Electrical Engineering*. Edgerton saw the value of his device as a tachometer, an instrument used to measure rotation rates, and submitted a patent application in 1933. In 1934, he contracted with the General Radio Company to produce his suitcase-size mercury-arc stroboscope, the Strobotach.

In 1928, Edgerton married Esther May Garrett, whom he first met when her family moved to Aurora, Nebraska, in 1915. They had three children, Mary, William, and Robert. During the summer of 1934, Edgerton and his family drove back to Nebraska for a visit. Edgerton stopped at factories on the route, trying to interest them in his Strobotach.

As word spread of his success in photographing rapidly moving objects, people visited Edgerton's laboratory seeking assistance on their own projects—initially, other faculty members who had research that might benefit from Edgerton's electronic flash. Edgerton credited MIT professor Charles Stark Draper with suggesting that he explore other uses for the strobe light. Draper told Edgerton, "The whole world is moving," inspiring Edgerton to take photographs of everyday objects and events. His first such photograph was a high-speed picture of water running from a faucet, highlighting the complexity of the motion. From then on, as Edgerton said, "it was just looking at one problem after another."

Edgerton and Kenneth Germeshausen, his research assistant, were both amateur photographers, so they began making still and motion pictures of all kinds of objects in rapid motion. These photographs showed everyday events in a way never before been seen. One photograph, taken in 1934, showing a football being placekicked, recorded the distortion of the football as the kicker's foot penetrated nearly halfway into the ball.

Three of Edgerton's photographs were included in the Royal Photographic Society's annual exhibition in London in 1933, the first time his photography was exhibited. Edgerton's most famous image is "Coronet," which shows in fine detail the symmetry of the splash made by a drop of milk striking a flat surface. That photograph was featured in the first-ever exhibit of photography at the Museum of Modern Art in New York City in 1937. Edgerton went on to photograph athletes in action; hummingbirds in flight; and bullets bursting balloons, cutting through playing cards, and penetrating a light bulb. Many of Edgerton's photographs were used as illustrations for articles in *National Geographic* and in *Life* magazines. In 1940, Edgerton was invited to Hollywood by MGM Studios to describe how his stop-action photography could be used in movies. This resulted in a short film, titled *Quicker than a Wink!* and starring Edgerton, which won an Academy Award.

Edgerton had formed a business partnership with Germeshausen in 1931. Together they improved on his original device. They wanted a brighter flash with an even shorter duration than the mercury arc could deliver. This effort resulted in the development of the xenon flashtube as a replacement for the mercury-arc source used in the original device.

Edgerton's electronic flash opened new avenues for the scientific study of the dynamics of fluids, air currents, and engines. During World War II, the U.S. Army sought Edgerton's help in developing an extremely bright flash for night aerial photography. The system Edgerton developed was used to monitor the night movement of enemy troops during the Battle of Monte Cassino in Italy and in the weeks before the Allied invasion of Normandy.

After World War II, Edgerton founded a company with Germeshausen and another of his research assistants, Herbert Grier. The company, now EG&G, received a contract from the Atomic Energy Commission

THE ELECTRONIC FLASH

The electronic flash is a device that produces a short, intense burst of light. The light pulse from an electronic flash can be used to "stop the motion" of a fast-moving object. The stroboscopic light is an electronic flash that produces a sequence of light pulses. The stroboscopic light can show a sequence of events, such as an insect flapping its wings, allowing the details of the motion to be studied.

Harold E. Edgerton's original electronic flash used a mercury-arc lamp. A large electric current passing through the mercury gas emitted a flash of light. However, the design quickly evolved as he sought to achieve a brighter flash of shorter duration, the modern electronic flash. This design consists of a gas discharge tube, a sealed cylindrical glass tube filled with inert gases. Electrical contacts at both ends of the tube are connected to a capacitor, a device that can store a large amount of electric charge. A battery or other electric power source is used to charge the capacitor. A high voltage is applied to the electrical contacts, ionizing the gas in the tube. These ions form a conductive path, and the capacitor releases its energy as an electric current through the tube, like a miniature lightning bolt. The flash ceases when the capacitor has used all of its stored energy. This discharge is very rapid, sometimes faster than one-millionth of a second. Once the current ceases to flow, the ions recombine with electrons that have been stripped off by the initial high voltage, and the flash is ready for use again. The choice of gas determines the color of the flash. Argon produces a bluish light, krypton reddish-green, and xenon a white flash resembling sunlight, making xenon ideal for photography.

to design timing and firing systems for atomic bomb testing. EG&G also developed a high-speed shutter for a camera that was used to photograph the explosion of atomic bombs, showing the structure of the intense fireball that developed as the atomic explosion propagated down the wires of the tower on which it was detonated.

In 1952, Edgerton developed an underwater camera for an expedition led by the underwater explorer Jacques Cousteau. Edgerton and Cousteau photographed the Romanche Trench, a deep trench in the Atlantic Ocean. Cousteau's crew nicknamed Edgerton "Papa Flash." On later expeditions with Cousteau, Edgerton participated in the location of the wreckage of the *Britannic*, a sister ship of the *Titanic* that was sunk by a German mine during World War I, as well as ancient wrecks. Edgerton faced the problem of determining the position of a camera when it was deep underwater. To solve this problem, he developed a special sonar, an underwater radar that sends out sound waves and detects their reflections. This led to Edgerton's pioneering work on side-scan sonar, which can profile the shapes of objects on the bottom of the sea.

Edgerton retired from MIT in 1968, when he reached the mandatory retirement age of sixty-five. However, he continued to teach and work in his research laboratory, called "Strobe Alley," for another two decades. In 1973, he recorded changes in the light and color of the solar eclipse in Akjoujt, Mauritania. That same year, he assisted a group using side-scan sonar to locate the wreck of the *Monitor*, the U.S. Navy's Civil War armored gunboat. Edgerton also participated in the search for the Loch Ness Monster in Scotland, using both special underwater cameras and sonar. As late as 1989, he was working on the design of a camera to be placed at the bottom of Loch Ness. Edgerton died of a heart attack in 1990.

IMPACT

Edgerton's work influenced science and engineering, artistic photography, and the public's perception of the world around them. The War Department awarded Edgerton the Medal of Freedom for this work during World War II. The strobe light that he developed has been incorporated into most cameras, from inexpensive models to sophisticated professional designs. His underwater cameras and side-scan sonar revolutionized undersea exploration. In 1988, the National Geographic Society awarded Edgerton its Centennial Award, naming him one of fifteen people worldwide who made major contributions to the knowledge of the earth, its inhabitants, and the natural environment during the first one hundred years of the society's existence. MIT preserved his Strobe Alley laboratory as a place for students and researchers to continue to explore applications of high-speed photography.

—*George J. Flynn*

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See also: George Eastman; Auguste and Louis Lumiére.

THOMAS ALVA EDISON

American technologist, scientist, and businessman

Edison is mainly known as the inventor of the phonograph and the light bulb. During his lifetime, he obtained more than one thousand U.S. patents. His other inventions include a motion-picture camera, a stock ticker, an electric pen, and numerous types of telegraphs, telephones, and electrical equipment. He also developed complete power systems, business organizations, commercialization strategies, and the modern research laboratory.

Born: February 11, 1847; Milan, Ohio
Died: October 18, 1931; West Orange, New Jersey
Primary fields: Entertainment; manufacturing
Primary inventions: Light bulb; phonograph; kinetoscope

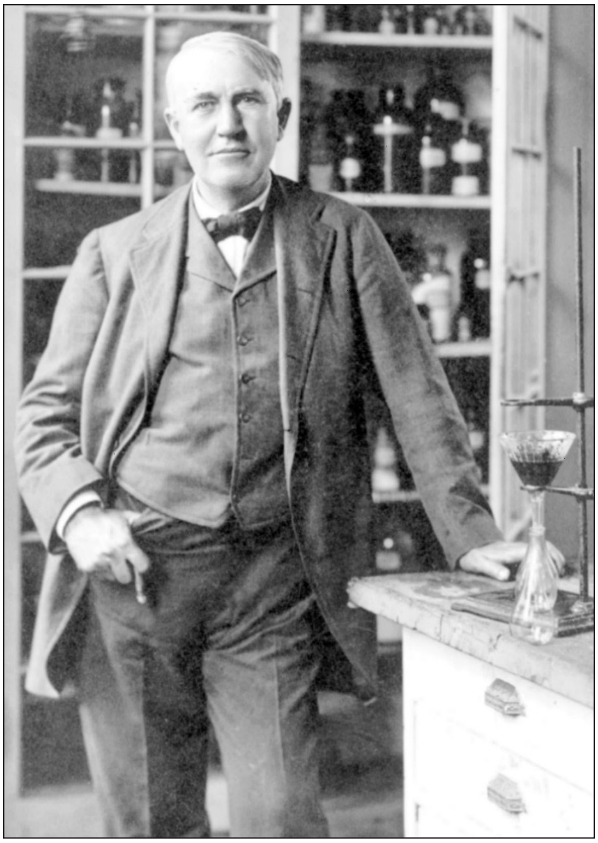
EARLY LIFE

Thomas Alva Edison was born to Samuel and Nancy Elliott Edison in the small town of Milan, Ohio, in 1847. In 1854, the family moved to Port Huron, Michigan. Like Milan, Port Huron was small but served as a local center for commerce and industry. From an early age, Edison absorbed the local culture of artisans and workshops and read extensively in his father's library. He also inherited an entrepreneurial spirit from his father. He attended school for only three months in his youth and was then educated at home by his mother.

From an early age, Edison, called "Al" in his youth, loved to experiment and investigate. He set up a laboratory in his parents' basement. In 1859, he took a job selling candy, magazines, and newspapers on the Grand Trunk Railroad running between Port Huron and Detroit. He spent his layover time in Detroit reading at the Detroit Public Library and performed chemistry experiments in the baggage car. One mishap in his chemical "laboratory" nearly burned the car. In his later writings, Edison states that it was during this time that he first noticed his hearing problem. As an adult, he became almost completely deaf.

In April, 1862, Edison demonstrated an entrepreneurial instinct that would serve him well later. News of the Civil War had increased his newspaper sales. On the day of the Battle of Shiloh, he saw the bulletin boards at the Detroit station surrounded by large crowds reading the announcements that 60,000 soldiers were killed and wounded. He decided that, if the same excitement were present at the small towns on the railroad, sales of papers would increase. He had the telegraph operator at Detroit telegraph the news on the battle to each station on the route to Port Huron. With the approval of the editor of the paper, Edison took along one thousand papers rather than the usual hundred. At one station where he normally stopped, he sold thirty-five papers. Edison raised the price of the newspaper at each station because there were crowds awaiting news. The papers he usually sold for five cents had gone up to twenty-five cents by the time he reached Port Huron. He made a great deal of money and began learning telegraphy the next day.

After Edison rescued the son of a telegraph operator from the path of a freight car in 1862, the operator rewarded him by giving him telegraph lessons. Edison first took a part-time job as a telegrapher in Port Huron. He eventually became an itinerant telegrapher and quickly became known as an expert receiver. He worked in several midwestern cities and continued his reading in tech-



Thomas Alva Edison. (Library of Congress) nical and scientific literature. He spent much of his time thinking about how to improve telegraphy, which was a crude communication system at that time. To send a message from Boston to St. Louis required a chain of six operators.

In 1868, Edison moved to Boston and took a job with Western Union. He found financial backers in the telegraph community and worked on improving the telegraph. He obtained his first two patents—a vote recorder, which the state legislature would not buy, and a printing telegraph for stock quotations. The stock ticker proved more successful, and Edison left his job and devoted himself full-time to inventing.

LIFE'S WORK

Edison's professional career as an inventor took off when he visited New York City in 1869 to test an improved telegraph. After meeting Franklin Pope, a prominent telegraph engineer, Edison moved to New York. Pope and Edison set up a series of businesses to invent and promote printing telegraphs, which played a key role in the distribution of financial information. Edison sold a printing telegraph, or stock ticker, to Western Union. The profits allowed him to set up a large laboratory in Newark, New Jersey.

Between 1870 and 1876, Edison worked on telegraph improvements such as an automatic telegraph system, which did not require an operator to take down the message. He also developed a quadruplex telegraph, which would allow two messages to be sent in one direction and another two in the opposite direction over a single wire. This increased the capacity of a wire fourfold. He invented an electric pen, which made an exact copy of something that a person wrote. Both the quadruplex telegraph and the electric pen brought substantial profits, with which Edison expanded his laboratory and business.

In 1871, Edison married Mary Stilwell. Between 1873 and 1878, they had three children: Marion, Thomas, and William. However, Edison's work remained the most important aspect of his life. His work habits included long hours away from his family. He often worked late, took short naps rather than sleeping through the night, and ate around midnight.

A replica of Thomas Alva Edison's light bulb from 1879. It used a carbonized-thread filament that burned for forty hours. (The Granger Collection, New York)

In 1876, Edison took his family and his work to Menlo Park, New Jersey. There he built a new home and a laboratory solely for conducting experiments. This became an unparalleled facility for invention. Edison enjoyed the mental work, the creative part of the process of invention. He would have an idea, draw up a rough sketch, and discuss it with his assistants. They would examine the sketch and work with it until they could turn it into a workable machine.

The "invention factory" set up at Menlo Park produced the phonograph, the light bulb, a power distribution system that would bring electricity into homes, and a greatly improved telephone. Western Union, for which Edison continued to do work on improving the telegraph, was concerned about the competition from the telephone and asked Edison to work on an improvement. He improved the quality of the sound and made the telephone much easier to use by providing a separate mouthpiece and earpiece. He also developed a transmitter that would carry over longer distances and that was used for nearly a century. The telephone improvements netted Edison's company over a quarter of a million dollars.

An unexpected outcome of the telephone re-

THE LIGHT BULB AND ITS POWER SYSTEM

Thomas Alva Edison invented an electric light and an electric distribution system to power it. This invention began with a search for a lamp to replace gas lighting, which could be dangerous with the open flame. Another alternative, arc lighting, had proven more successful for outdoor lighting than for indoor, where it could give off dangerous sparks and provided too intense a light for small spaces. Others had tried unsuccessfully to develop an incandescent light bulb. However, Edison's "invention factory" system at Menlo Park, New Jersey, proved equal to the task.

The first problem with inventing a practical incandescent bulb was the filament. Most materials burned up too fast and could not give long, steady light. Edison and his team tried thousands of materials for more than a year. They began in September, 1878, with platinum wire filaments, which had a high melting point. To deal with this problem, they enclosed the filament in a vacuum bulb. However, a platinum filament would make the bulbs too expensive for wide use and require large and expensive copper-wire conductors in the power distribution system because of platinum's low resistance to the electric current. Edison realized that a system of incandescent lighting required high-resistance lamps in order to reduce the size and cost of copper conductors. With a good vacuum bulb, Edison turned to carbon for filaments. The successful choice of filament came by accident when Edison abstractedly rolled a piece of compressed lampblack between his fingers until it became a slender thread. Seeing this, he tried it as a filament. With a few further experiments, he found the right composition of materials. On October 21-22, 1879, Edison and his team tested the first successful incandescent lamp in a vacuum with a piece of carbonized thread as filament. Soon they began demonstrating it, but they continued to work on improving the filament. Within a year, Edison's company began producing commercial bulbs with a filament of carbonized Japanese bamboo.

Meanwhile, Edison focused more on inventing the electrical distribution system to power the bulb. His light bulb would only succeed commercially if numerous homes and offices had access to electricity to use the new light source. Edison modeled his distribution system on that of gas lighting, which included central stations, underground conductors, meters, and lamp fixtures. He also designed almost everything in the system, including a new electrical generator, new screw sockets to hold the bulb in the fixtures, and fuses to prevent electrical overloads.

The first permanent central station opened in Manhattan in 1882. It served Wall Street and many of the major newspapers. Edison invented a new lamp and electric distribution system that would change the world. However, eventually his system shifted from direct current, which Edison strongly defended, to alternating current. Edison's direct-current system worked efficiently in densely populated cities. However, alternating current could travel longer distances. By 1891, Edison had left behind the industry that he had helped found. His company merged into General Electric.

search was the invention of the phonograph in 1877. The telephone was originally envisioned as a way for telegraph companies to transmit messages between operators. However, speech was too fast to be written down. Edison devised a way to record the vibrations in the receiving instrument and play them back slower to record the words. This led Edison and his staff to realize that they could record sound, and the invention of the phonograph followed. The phonograph recorded and played back both words and music. While the phonograph made Edison an overnight celebrity (he was billed in the press as the "Wizard of Menlo Park"), he was unable to turn his early exhibition machine into a commercial product.

Edison brought together everything he had learned about invention and business in the development of the light bulb and the electric light and power system, beginning with a search for a lamp to replace gas lighting. Edison pulled together financial backing, numerous researchers, an expanded laboratory and shop facilities, factories, and marketing. The search for a filament took an enormous amount of time and resources. However, the demonstration of the first working light bulb in 1879 was only the beginning. Most homes did not have access to the electricity necessary to use the light bulb. Edison's laboratory then developed an electric power distribution system and opened the first electric power plant in New York in 1882. By the end of the nineteenth century, there would be over five hundred Edison plants in the United States and at least fifty in other countries.

In 1884, Edison's wife died after a long period of illness. Although work had always taken first place with Edison, he was devastated by her death. Within a year, he moved the family away from Menlo Park. In 1886, he married Mina Miller and moved his family and business to West Orange, New Jersey. There he created a laboratory that would set the example for research and development laboratories in the twentieth century.

With the invention of the kinetoscope in the late 1880's, Edison founded the American motion-picture industry. Edison and one of his trusted assistants, W. K. L. Dickson, began experimenting with celluloid film and found a way to do for images what they had done for sound. They recorded a series of images, each showing a tiny move forward. When viewed in rapid succession, the images gave the impression of movement. They developed a camera and the "peep-show" kinetoscope for viewing the films.

Although Edison's work as a businessman decreased over time, his inventive work continued for decades. Inventions included an improved phonograph, dictating machines, an improved storage battery, and a method for ore separation. Inventions such as the improved battery provided financial stability to Edison's laboratory and companies. Others, such as his magnetic ore separator, failed. Nevertheless, Edison persevered. He eventually became the nation's "inventor-philosopher," with reporters seeking his opinion on everything from diet to the existence of God.

He died at his home, Glenmont, in West Orange, New Jersey, on October 18, 1931. President Herbert Hoover asked the nation to dim its lights in his honor.

IMPACT

Edison changed the lives of Americans by bringing sound and light into their homes and businesses. While he became nationally and internationally famous upon his invention of the phonograph, some of his later inventions had a greater impact. The power distribution system that Edison developed to supply electrical power to his light bulb changed American homes forever. It not only provided light but also made possible the invention and use of numerous small household devices. Edison's inventions affected and sometimes created industries, including motion pictures, music, and electric power.

Edison's greatest contribution may have been the "invention of the method of invention," as Alfred North Whitehead called the greatest invention of the nineteenth century. Having begun his professional life as an independent inventor, Edison ended with perhaps the first modern research and development laboratory and team. His vision included what the twentieth century would term "innovation"—invention, research, development, and commercialization.

—*Linda Eikmeier Endersby*

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See also: Edward Goodrich Acheson; Ernst Alexanderson; Alexander Graham Bell; Emile Berliner; Karl Ferdinand Braun; William David Coolidge; Reginald

Aubrey Fessenden; Peter Carl Goldmark; Elisha Gray; H. Tracy Hall; David Edward Hughes; Miller Reese Hutchison; Eldridge R. Johnson; Lewis Howard Latimer; Auguste and Louis Lumière; William Murdock; Christopher Latham Sholes; Frank J. Sprague; Joseph Wilson Swan; Nikola Tesla; Elihu Thomson; Mark Twain; George Westinghouse; Granville T. Woods.

Albert Einstein

German American theoretical physicist

Einstein's special and general theories of relativity forever changed the scientific conceptions of space, time, mass, energy, and gravity. Those theories, along with quantum theory, constitute the foundation of all modern physics.

Born: March 14, 1879; Ulm, Württemberg, Germany
Died: April 18, 1955; Princeton, New Jersey
Primary field: Physics
Primary invention: Special and general theories of relativity

Early Life

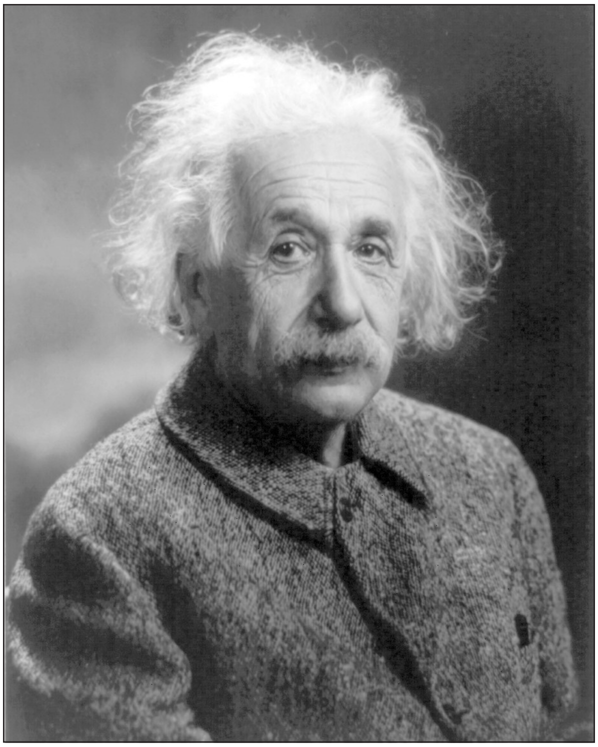
Albert Einstein (IN-stin) was born to Hermann and Pauline Koch Einstein in their home at Bahnhofstrasse 135, Ulm, Germany, in 1879. Early fears for his mental development, primarily due to a skull unusual in size and shape along with a significant delay in learning to speak, eventually dissipated as he grew and matured normally. His elementary and high school performances were unremarkable. In a series of autobiographical sketches written late in life, he mentioned two "miracles" that established his lifelong interest in physics and mathematics. At the age of four or five, his father showed him a compass that excited him greatly and inspired deep curiosity about the inner workings of the physical world. At twelve, he received a book on Euclidean geometry. Impressed by the clarity and certainty of mathematical proofs, he quickly mastered the subject and then proceeded to teach himself differential and integral calculus.

Einstein's family moved to Milan, Italy, in June of 1894, leaving Albert behind to finish school. The following spring, Einstein left Germany to escape conscription into the army. He spent the summer of 1895 with his family in Italy, attempting to enroll in the Federal Institute of Technology in Zurich, Switzerland. He failed the entrance examination and was advised to obtain a Swiss high school diploma that would allow him to enroll in the institute. He chose a school in Aarau, obtaining a diploma and registering at the institute in October, 1896.

At the institute, Einstein was an indifferent if not difficult student. He skipped class often, preferring to teach himself from available books. He kept up with material covered in class by borrowing his fellow classmates' notes. He graduated without any apparent distinction in August, 1900, and found that no one wanted to hire him.

Einstein married Mileva Marić, a fellow student at the institute, on January 6, 1903. A daughter born to the two before marriage was given up for adoption; her subsequent life is unknown. Mileva delivered a son, Hans Albert, on May 14, 1904, and a second son, Eduard, on July 28, 1910.

After graduation, Einstein held a series of temporary jobs. On June 16, 1902, he obtained a permanent position with the Swiss Patent Office that he retained until accept-



Albert Einstein. (Library of Congress) ing a university professorship in October, 1909. His duties at the patent office were light and left with him a great deal of time to think about physics.

LIFE'S WORK

In 1905, called Einstein's "miracle year," the twenty-six-year-old amateur physicist published a series of groundbreaking papers in the prominent science journal *Annalen der Physik*. His first paper explained the photoelectric effect using Max Planck's quantum theory of radiation. This paper formed the basis for much of quantum mechanics. His second paper dealt with Brownian motion, the random motion of microscopic particles suspended in a fluid such as water. Einstein explained it as the result of uneven pushes delivered by random collisions with molecules. His paper provided evidence for the existence of atoms.

His third paper addressed special relativity, treating the constancy of the speed of light as a fundamental scientific principle for the first time. This paper demonstrated that moving clocks will appear to run slow relative to clocks at rest (time dilatation) and that moving objects will appear shortened in the direction of their motion (Lorentz-Fitzgerald contraction). The special theory of relativity eliminated the need for a mechanical substance to support light waves (the "ether"). It also abolished the notions of absolute space and time: Motion can only be described relative to other objects; all observers do not perceive time in the same universal way.

A 1906 paper on the specific heat of solids was the first application of the new quantum theory to the solid state of matter. In one year, Einstein had invented an entirely new branch of physics (relativity) and made signif-

SPECIAL AND GENERAL THEORIES OF RELATIVITY

During the late 1800's, many physicists recognized that James Clerk Maxwell's equations for electromagnetism were incompatible with the concepts of space and time underlying Sir Isaac Newton's three laws of motion. Attempts to explain electromagnetic waves (light and the newly discovered radio waves) as vibrations in an elastic substance called the "ether" predicted properties for light that could not be found experimentally.

Albert Einstein recognized that a key property of Maxwell's equations predicted that the speed of light must be constant for all observers under all circumstances. Einstein accepted this implied property of light as a postulate and followed this assumption to its inevitable conclusions. By applying this postulate to a simple clock based on the travel time of light pulses, he showed that time as measured by this clock (and by implication, all clocks) in motion must appear to an observer at rest to run slow. By careful consideration of how clocks are synchronized and how distances are measured, Einstein deduced that moving objects must appear to an observer at rest to shrink along the direction of motion. All of these effects were captured in a set of transformation equations that allowed lengths and times for a moving observer to be calculated from the corresponding lengths and times as seen by a stationary observer, and vice versa. These equations had already been worked out by Hendrik Lorentz in his theory of the electron, but Einstein's independent derivation from the constancy of the speed of light was a powerful argument for the validity of special relativity.

In a later paper, Einstein examined how the emission of light (a form of energy) from a body at rest would look to a moving observer whose standards of time and length would be affected by the motion. Einstein deduced that the energy of the light would have to come from a reduction in the mass of the body. The amount of energy released would be equal to the lost mass multiplied by the square of the speed of light (the famous $E = mc^2$ formula). This equivalence of mass and energy had been worked out for special cases as early as 1880. Einstein showed it to be a general property, true for all of physics.

It quickly became clear that gravity was a problem in special relativity. Einstein realized that on a small enough scale that gravity is indistinguishable from acceleration: An observer locked inside an elevator cannot determine whether the elevator is accelerating upward or is stationary in a constant gravitational field. Unifying this principle with special relativity occupied Einstein for the next ten years. Hermann Minkowski's insight of uniting time with three-dimensional space to make four-dimensional space-time proved crucial. At first, Einstein dismissed the space-time approach as useless theorizing, but it proved to be essential to his quest for a relativistic theory of gravity.

This work culminated in the general theory of relativity. General relativity treats space-time as a non-Euclidean geometry ("curved space"). Familiar Euclidean space is "flat," with no curvature: Unaccelerated objects move on straight lines. What appears in ordinary three-dimensional space to be a gravitational acceleration is actually motion along an unaccelerated but curved path in the non-Euclidean four-dimensional space-time.

icant pioneering discoveries in two other fields (statistical physics and quantum theory).

Einstein turned to the nature of gravity and its compatibility with special relativity in 1907, when he discovered the principle of equivalence, one of the cornerstones of the general theory of relativity. The concept states that uniform accelerations are almost indistinguishable from gravity. It took Einstein almost ten years to develop the mathematics that properly describe the equivalence principle. The general theory of relativity reached its final form in 1915 and was published in early 1916. General relativity regards gravity as a curvature of space and time, united in a four-dimensional space-time.

No theory this radical will get any respect from other scientists unless it makes some testable predictions. Einstein applied this new theory to the motion of the planets and for the first time explained an anomalous advance in the perihelion (the point of a planet's closest approach to the Sun) of the planet Mercury. Applying it to his favorite subject, light, Einstein showed that general relativity predicts that light should follow a curved path when passing near a strong gravitational source and that light should lose energy and increase in wavelength when climbing out of a gravitational field. This last effect is referred to as a "redshift" because light in the visible spectrum becomes redder as the wavelength becomes longer. It also implies that clocks at high altitudes will run slightly faster than clocks at low altitudes, an effect known as gravitational time dilatation.

The anomalous precession of Mercury had long been known to astronomers, and Einstein used it as a test of general relativity while developing the theory. Observation of a total solar eclipse in 1919 detected a gravitational deflection of starlight as it passed near the Sun, confirming Einstein's prediction, and spectral analysis of starlight from the white dwarf companion of Sirius confirmed the gravitational redshift of light. Modern experiments with atomic clocks have detected and measured gravitational time dilatation.

Announcement of the 1919 eclipse results brought Einstein worldwide fame. He was awarded the 1921 Nobel Prize in Physics for his work on the photoelectric effect and other contributions to physics; special and general relativity were both still considered too controversial to acknowledge. He and Mileva had moved to Berlin in 1914 and separated shortly thereafter, with the divorce finalized on February 4, 1919. Einstein married his divorced cousin, Elsa Lowenthal, on June 6, 1919. They remained together until her death on December 20, 1936.

Rising anti-Semitism in Germany began to impact Einstein's life and work from 1920 on. When the Nazis came to power in 1930, Einstein, his wife, and several family members and close friends emigrated to the United States after a short stay in Belgium. Einstein spent the rest of his life at the Institute for Advanced Study in Princeton, New Jersey, dying of an abdominal aneurysm at 1:15 A.M. on April 18, 1955.

IMPACT

Einstein's special theory of relativity was consistent with the work of many theoreticians working on the paradoxes of electromagnetism. It elegantly tied many of their partial results into a coherent theory and was readily accepted by them. As years passed, more and more researchers extended the theory and began using it to explain anomalous experimental results. In particular, the relativistic equivalence of mass and energy, formulated by Einstein in one of his 1905 papers, explains the enormous amounts of energy released in radioactive decay, nuclear fission, and nuclear fusion. Special relativity in quantum mechanics explains the fine structure of atomic spectra and the existence of antimatter. (Carl Anderson discovered the positron, the first antiparticle, in 1932.)

In 1916, Karl Schwarzschild used general relativity to predict the existence of black holes. Edwin Hubble discovered the expansion of the universe in 1924, a phenomenon best explained by general relativity. In 1930, J. Robert Oppenheimer used general relativity to predict the existence of neutron stars, discovered in the form of pulsars in 1965. The Hubble Space Telescope continues to discover "Einstein lenses" formed by the gravitational effect of galaxies on light from more distant objects. The images formed from these galactic lenses are all the information available on some of the most distant objects in the cosmos.

Atomic clocks have become so accurate that relativistic time effects, both special and general, are easily measured. The U.S. Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS) must both correct for the effects of special and general relativity in order to provide users with accurate position data.

—*Billy R. Smith, Jr.*

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See also: John Bardeen; Walther Bothe; Raymond Damadian; Charles Stark Draper; Michael Faraday; Enrico Fermi; Dennis Gabor; Galileo; Leopold Godowsky, Jr.; Gordon Gould; Heinrich Hertz; Ali Javan; Gottfried Wilhelm Leibniz; Hudson Maxim; Naomi L. Nakao; Sir Isaac Newton; Hans Joachim Pabst von Ohain; J. Robert Oppenheimer; Stanford Ovshinsky; Wilhelm Conrad Röntgen; Charles Proteus Steinmetz; Theodor Svedberg; Leo Szilard; Charles Hard Townes; Ernest Thomas Sinton Walton.

WILLEM EINTHOVEN

Dutch physiologist and physician

Einthoven developed the string galvanometer to measure the electrical currents in the human heart. His invention evolved into the modern-day electrocardiogram.

Born: May 21, 1860; Semarang, Java, Dutch East Indies (now Indonesia)
Died: September 28, 1927; Leiden, the Netherlands
Primary field: Medicine and medical technology
Primary invention: String galvanometer (electrocardiogram)

EARLY LIFE

Willem Einthoven (INT-hoh-vehn) was born in Semarang on the island of Java in the Dutch East Indies to Jacob Einthoven and Louise M. M. C. de Vogel. His mother was the daughter of the East Indies director of finance. Einthoven's father was originally from Groningen in the Netherlands and was stationed in the East Indies as a military surgeon. When Willem was ten, his father passed away, leaving a wife and six children. His mother moved the family back to the Netherlands and settled in Utrecht.

Einthoven was a very good student and entered the University of Utrecht in 1879. As a university student, he was physically active. He was the president of the Utrecht Gymnastics and Fencing Union and a founder of the student rowing club. While studying under the anatomist Willem Koster, and after sustaining a broken wrist while playing sports, Einthoven spent his recovery time thinking about the movements and functions of the arm joints. This resulted in his first published paper on the elbow joint in 1882. Einthoven's second study was his doctoral thesis. Under the guidance of his mentor, the great physiologist F. C. Donders, Einthoven became interested in electrophysiology. His research was conducted on the electrophysiology of the eye and he graduated cum laude with a medical degree in 1885. Although he is not remembered for his eye research, it was responsible for earning him his first academic appointment as professor of physiology at the University of Leiden in 1886. He was only twenty-five years old.

LIFE'S WORK

As a young professor, Einthoven continued his research in electrophysiology, now focusing on the respiratory system. Into the early 1890's, he studied asthma and the nervous control of the bronchial muscles. He published several studies in this area before beginning his most famous work, the electrophysiology of the heart.

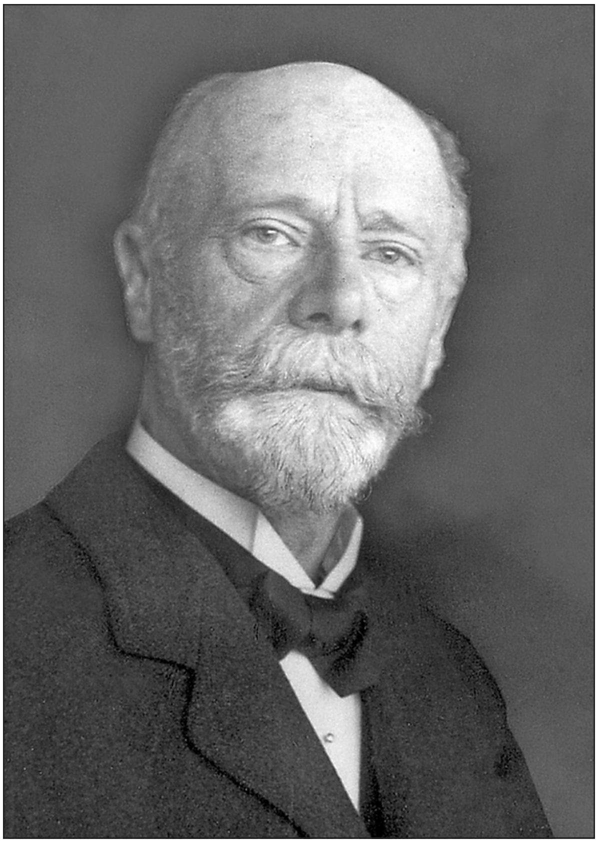
Einthoven's work on the heart was considerably influenced by his friend Augustus Waller. Waller published his research on the electrical changes of the heartbeat using a Lippman capillary electrometer in 1887.

This technique recorded the electrical activity of the heart by placing small tubes filled with mercury and sulfuric acid on the patient's chest. The mercury would expand and contract as the electrical current of the heart passed by the tubes. These movements were projected onto photographic paper to produce a cardiogram. This process was very tedious, and slight movements of the patient caused the mercury to move and make the tracings difficult to read. Even when good tracings were obtained, it took six or more hours to convert the data into a curve or cardiogram. These challenges, combined with the failure to find clinical applications, led Waller to abandon this research. However, Einthoven was more persistent.

In the early 1890's, Einthoven began using Waller's techniques in his laboratory, which was located in an old wooden building on a cobblestone street. Einthoven was further challenged by teams of horses passing by the building, causing vibrations of his capillary tubes placed on the patients' chests. One day, he became so irritated that he pulled up the floorboards, dug a deep hole, and lined the walls with rocks in an effort to minimize the movement. When this was unsuccessful, he also abandoned the Lippman capillary electrometer, but not the interest in the electrical activity in the heart.

Einthoven decided he needed a new instrument and began work with a d'Arsonval galvanometer. This instrument had a coil of wire suspended between the poles of a horseshoe magnet, but it was not sensitive enough to record the low-voltage activity of the heart. He replaced the wire with a string made of silver-coated quartz. The movements of the string were transmitted through a microscope and projected onto photographic film. His new instrument was called the string galvanometer, and its applications were published in 1901.

Einthoven set out to show the clinical significance of his string galvanometer. He began to test individuals with known heart problems to see how the tracings differed. Since the hospital was over a mile from his laboratory, Einthoven had the two buildings connected by a telephone wire. This allowed patients in the hospital to be tested and the tracings made in his lab. In 1906, he published one of his most important works, which showed the different tracings for heart ailments that included premature contractions of the heart, several different types of blocks in the conduction system, and enlargements of the chambers. He also studied the effects of specific cardiac drugs on the electrical events in the heart. In 1913, he published the improvements in the string galvanometer and a technique for determining the axis of the heart.



Willem Einthoven. (©The Nobel Foundation)

Einthoven corresponded with many researchers of his time, but one noteworthy physician was Sir Thomas Lewis. Lewis used Einthoven's electrocardiogram to identify other heart abnormalities, including atrial fibrillation—when the upper chambers of the heart become overexcited. Lewis's most significant contribution came during World War I, when he used the electrocardiogram to test the hearts of soldiers during exercise. He was able to identify heart problems that could not be diagnosed during rest. Einthoven credited Lewis with increasing general interest in his electrocardiogram.

In 1924, Einthoven visited the United States to demonstrate his instrument to researchers and physicians at several institutions, including Harvard and Johns Hopkins universities. While visiting, he learned that he was awarded the Nobel Prize in Physiology or Medicine. Since he was so far from Stockholm, he was unable to receive his award that year and officially accepted it in 1925. After receiving the Nobel Prize, Einthoven continued his work on the electrocardiogram and studied general electrophysiology of other systems in the body.

Einthoven passed away in Leiden in 1927 at the age of sixty-seven.

IMPACT

Although Einthoven was a research physiologist, he was also an engineer. In order to study the electrophysiology of the heart, he had to develop and refine the equipment needed to do his research. As he perfected the string galvanometer and published his work in the early 1900's, he generated much interest in his invention. By 1910, his instrument became known as the electrocardiogram and was being used in other countries, including the United States. A new laboratory at Johns Hopkins University was the first in the United States to install the electrocardiogram to study heart disease.

In the 1920's, the electrocardiogram used four electrodes that were placed on the arms and legs. Three electrodes were used to form three leads. The right leg electrode was used as a ground to minimize electrical interference. Einthoven's original invention was improved after his death in the 1930's. Researchers at the University of Michigan led by Frank N. Wilson combined the three electrodes in a different way to form three additional leads. Six new electrodes were eventually added to increase the total leads to twelve. These modifications made the electrocardiogram a much better diagnostic tool for the heart. Computer advances have made the electrocardiogram, also known as ECG or EKG, smaller and easier to use. Einthoven's ECG is now found in virtually all hospitals and clinics and is one of the major procedures used to diagnose ailments of the heart.

—*Bradley R. A. Wilson*

THE ELECTROCARDIOGRAM

Willem Einthoven developed the first instrument that could consistently measure the electrical activity of the heart with precision. Initially, he used the electrometer developed by Augustus Waller. The output of this instrument formed curved lines (waves) that had points labeled A, B, C, D, E. The electrometer, however, was very difficult to use; therefore, Einthoven began to develop the electrocardiogram in order to measure the electrical activity of the heart more easily. This instrument also produced waves, and Einthoven named them P, Q, R, S, T. He did this because the points on curved lines in geometry are labeled beginning with the letter *P*. To this day, the labels Einthoven developed are used to identify the waves of the electrocardiogram.

The P wave reflects stimulation of the atria (upper chambers of the heart). The QRS complex reflects stimulation of the ventricles (lower chambers). The QRS complex is much larger than the P wave because the ventricles are bigger and have more muscle mass than the atria. During ventricular recovery, the T wave forms. The atria also must recover, but this happens at the same time that the ventricles are stimulated, so no wave is seen. If there is a problem with the atria, the P wave will look abnormal; if there is a problem with the ventricles, the QRS complex will look abnormal. The type of changes in the waves tells the clinician what is wrong, if anything, with the heart.

The electrocardiogram changed the way heart problems were diagnosed. It is easy to perform the test, and it is noninvasive. Since Einthoven's time, many other instruments and procedures have been developed for the heart, such as the echocardiogram and cardiac catheters, but the electrocardiogram is ubiquitous in hospitals because it is quick, simple, inexpensive, and noninvasive. If a patient comes to the hospital with chest pains, one of the first procedures performed is an ECG.

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See also: Wilson Greatbatch; Ida H. Hyde; Robert Jarvik; Gabriel Lippmann.

GERTRUDE BELLE ELION
American biochemist and pharmacologist

Elion invented a revolutionary drug research methodology that focused on how normal and abnormal cells reproduce. This enabled her to develop target-specific drugs that killed or suppressed abnormal cells or pathogens without damaging normal cells.

Born: January 23, 1918; New York, New York
Died: February 21, 1999; Chapel Hill, North Carolina
Primary fields: Chemistry; medicine and medical technology
Primary inventions: Purinethol; azathioprine

EARLY LIFE

Gertrude Belle Elion (EHL-ee-on) was born into a religious and scholarly family in New York City in 1918. Her father, Robert Elion, had emigrated from Lithuania when he was twelve. Descended from a long line of rabbis, he became a dentist. Elion's mother, Bertha Cohen, was fourteen when she emigrated from Russia, and her family included biblical scholars. Elion and her younger brother Herbert had a happy childhood and received a sound education in the public schools. An outstanding student who had an insatiable desire for knowledge in all subjects, Elion especially enjoyed science books. She admired inventors, such as Louis Pasteur and Marie Curie.

A turning point in Elion's life occurred when she was fifteen years old and her beloved grandfather died a slow, agonizing death from cancer. Elion vowed to find a cure for the disease. In 1933, she became a chemistry major at Hunter College, the women's branch of the City College of New York. Fortunately, Hunter College was free and Elion had high grades. Otherwise, she would not have been able to attend college, since her family had become bankrupt during the stock market crash of 1929.

In 1937, Elion graduated with highest honors. A doctorate was required to become a chemical researcher, so Elion applied for scholarships or assistantships to graduate schools. Her applications were rejected, and jobs in research labs were scarce. She applied for a laboratory position for which she was qualified, but the interviewer thought a woman would be too distracting. At this point, Elion finally realized that there was gender discrimination in the sciences.

Eventually, she found work as a lab assistant, without pay at first. By 1939, she had some savings and was able

Gertrude Belle Elion, cowinner of the 1988 Nobel Prize in Physiology or Medicine. Her research led to the development of drugs effective against cancer, AIDS, and organ transplant rejection. (©The Nobel Foundation) to start graduate school at New York University, where she was the only female in the chemistry class. She earned a master of science degree in chemistry in 1941.

LIFE'S WORK

Meanwhile, another tragedy occurred. In 1941, her fiancé, Leonard Canter, died of acute bacterial endocarditis, an infection of the inner lining of the heart. Penicillin, which would have saved his life, was not used as a drug until years later. She never married, and this personal loss further intensified her lifelong desire to cure diseases.

After World War II began, men were called to support the war effort, and more jobs became available to women. There was a shortage of industrial chemists, so Elion was able to find work as a quality-control chemist for the Quaker Maid Company in 1942. She learned about instrumentation, but the work was repetitive: She checked the acidity of pickles, the color of mayonnaise, and the mold levels of fruit. After a year and a half, she found a research job synthesizing sulfonamides at Johnson and Johnson, but the laboratory closed after six months.

In 1944, Dr. George Hitchings hired Elion to be his research assistant at Burroughs Wellcome (now GlaxoSmithKline), a pharmaceutical company in Tuckahoe, New York. From the beginning, Hitchings was impressed with Elion, and she was fascinated by his research in nucleic acid biochemistry. Thus began one of the most productive and famous collaborations in history. Hitchings encouraged her to follow her instincts, work independently, and publish papers. Although he guided Elion and reviewed her papers, he listed her name first on papers she wrote. She would continue that tradition with her own assistants in the future. Over the course of her career, she published more than 225 papers. Hitchings and Elion worked together for more than four decades and revolutionized medicine and pharmacology. Their research involved immunology, microbiology, and virology, as well as organic chemistry.

The traditional method for developing new drugs was a trial-and-error process in which new compounds were tried out on a target, usually a mouse. Hitchings and Elion used a new rational scientific approach requiring less time and speculation. They focused on how cells reproduce at various stages and studied the differences between the biochemistry of normal human cells and those of bacteria, tumors, and other pathogens (disease-causing agents).

In 1944, biochemist Oswald Avery discovered that deooxyribonucleic acid (DNA) was the carrier of genetic information (genes and chro-

PURINETHOL

Gertrude Belle Elion changed the way drugs are discovered with the new methodology that she and Hitchings created. They compared normal and abnormal cell metabolism and reproduction and then created antimetabolites to interfere with the life cycle of abnormal cells without harming normal cells. Elion focused on the purine bases (adenine and guanine), which are two of the four bases that are part of the larger nucleic acid (DNA) molecule, which carries genetic information.

Using this methodology in 1950, Elion synthesized a cancer drug, diaminopurine, which interfered with the metabolism of leukemia cells (abnormal white blood cells). It produced a complete remission in an acutely ill leukemia patient who had a relapse after two years and died. Saddened, Elion then made and tested over one hundred compounds. Finally, she substituted a sulfur atom for the oxygen atom on a purine molecule and made 6-mercaptopurine (6-MP), the first effective leukemia drug.

Elion's 6-MP (marketed as Purinethol in the United States) was the first childhood leukemia drug capable of causing a complete, though temporary, remission. Before the development of this drug, 50 percent of all children with acute leukemia died within three to four months. Eventually, a combination of 6-MP with other drugs could effectively cure childhood leukemia. By the early 1990's, the 6-MP therapy could cure 80 percent of patients with acute lymphoblastic leukemia.

6-MP also suppressed the immune system, which had implications for organ transplant surgery. In 1959, Robert Schwartz tested 6-MP on rabbits injected with a foreign compound, and the drug prevented their immune systems from producing antibodies. Then, the British surgeon Roy Calne used 6-MP on dogs receiving kidney transplants; the dogs given the drug outlived the dogs who did not receive 6-MP.

Elion remembered that she had synthesized azathioprine (Imuran), a complex version of 6-MP, and that this related compound did not affect cancer cells but was a better immunosuppressant than 6-MP. Calne then used Imuran for a successful organ transplant on a collie named Lollipop. Using the same drug, Dr. Joseph Murray performed the first successful kidney transplant between unrelated people in 1962. In the 1960's, Elion also developed allopurinol (Zyloprim), another compound related to 6-MP. This drug was effective for treating gout and many diseases occurring in South America.

mosomes). However, it was not until 1953 that James Watson and Francis Crick discovered the double helix structure of DNA. Thus, not much was known about nucleic acids at that time, but Hitchings and Elion understood that DNA was the essence of life and that all cells required nucleic acids to reproduce. Nucleic acids carry the information each living thing inherits from its parents. That information tells the cell how to carry out its activities and is coded in small molecules called bases.

Elion and Hitchings realized that if they slightly changed the natural bases, or DNA building blocks, in a cell so that the altered bases could not be used to make new nucleic acids, then these new bases would act as antimetabolites, chemicals that prevent cell metabolism. Mistaking these antimetabolites for natural bases and incorporating them, viruses, cancer cells, and pathogens would be poisoned and unable to reproduce or carry out their own chemical activities, thus stopping the spread of disease without harming normal cells. Elion and Hitchings called these false bases “rubber donuts” because they looked real but did not work.

In 1950, at the age of thirty-two, Elion synthesized two cancer drugs, diaminopurine and thioguanine, by using these methods. She also developed 6-mercaptopurine (Purinethol), the first effective treatment for childhood leukemia. Through the years, she invented many other life-saving drugs: azathioprine (Imuran), the first immunosuppressive agent used for organ transplants; allopurinol (Zyloprim) for gout; pyrimethamine (Daraprim) for malaria; trimethoprim (Septra) for meningitis, septicemia, and bacterial infections of the urinary and respiratory tracts; and acyclovir (Zovirax) for viral herpes.

Elion retired in 1983 but remained active in education and scientific organizations. Along with Hitchings and Sir James Black, she received the 1988 Nobel Prize in Physiology or Medicine. In 1991, she received the National Medal of Science and also became the first woman to be included in the National Inventors Hall of Fame. Although she never had time to finish her doctorate, George Washington University, Brown University, the University of Michigan, and other schools awarded her honorary doctorates. Elion died at the age of eighty-one on February 21, 1999.

IMPACT

The new drug-making methodology developed by Elion and Hitchings led to new drugs no one had ever thought possible. The holder of forty-five patents, Elion invented or helped develop the first effective drugs for an extraordinary range of diseases. When she discovered a compound, she explored all its implications and used it to find more information and to discover compounds against other diseases. Her innovative approach profoundly affected the whole field of drug development and became the standard in pharmaceutical research.

Elion’s immunosuppressive drug, azathioprine, which could be used to prevent a patient’s immune system from rejecting a transplanted organ as a foreign invader, made organ transplant surgery possible. Transplant operations have since become routine. By 1990, over 200,000 kidney transplants had been performed worldwide. In 2006, there were over 17,000 kidney transplants in the United States and an overall total of over 28,000 transplants, including pancreas, liver, intestine, kidney-pancreas, heart, heart-lung, and lung. By May, 2008, there were 99,258 people on the waiting list for an organ.

Elion’s antiretroviral drug led to her research laboratory’s development of azidothymidine (AZT), the first drug treatment for acquired immunodeficiency syndrome (AIDS), in 1984. Until 1991, AZT was the only drug approved for the treatment of AIDS. Her developments in cancer drugs have had a lasting impact on cancer research. She laid the foundation for the discovery of future cancer treatments, such as nelarabine (Arranon), a cancer drug licensed in the United States in 2005 to treat certain rare forms of leukemia and lymphoma when patients have exhausted standard options. The multitude of drugs invented by Elion continue to save countless lives every day throughout the world, and her humanistic spirit inspired future generations of scientists.

—*Alice Myers*

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See also: Robert Charles Gallo; Percy Lavon Julian.

PHILIP EMEAGWALI

Nigerian American computer scientist

Hailed as one of the fathers of the Internet, Emeagwali introduced a method to track oil flow underground using a supercomputer. His groundbreaking experiment benefited the oil industry and demonstrated the possibilities of computer networking.

Born: August 23, 1954; Akure, Nigeria
Also known as: Philip Chukwurah Emeagwali (full name)
Primary fields: Computer science; mathematics
Primary invention: Method for simulating oil reservoirs

EARLY LIFE

Philip Chukwurah Emeagwali (eh-MAY-ah-gwah-lee) was born August 23, 1954, in Akure in southwestern Nigeria. He was the first of nine children born to sixteen-year-old Agatha Emeagwali, a homemaker, and thirty-three-year-old James Emeagwali, a nurse's aide. As the oldest child of the poor family, Philip had numerous duties that required him to rise at 4:00 A.M. to help out. When Philip was nine years old, James, recognizing his son's special talent in mathematics, reduced his chores, allowing him more time to study mathematics. James frequently gave Philip one hundred math problems to complete in his head in an hour—an average of thirty-six seconds per problem—to improve his mathematical skills.

At age ten, Emeagwali took his high school entrance exam, receiving a perfect score in the mathematics section, and was promptly disqualified for fraud because authorities considered his accomplishment impossible. At the all-boys Catholic high school, Emeagwali, nicknamed "Calculus," studied languages, literature, geography, biology, and mathematics. After a little over a year there, the Igbo tribe to which the Emeagwali family belonged became embroiled in ethnic conflicts that killed one million people. The surviving tribal members lived in refugee camps in eastern Nigeria until the war ended. Emeagwali dropped out of school for three years but continued studying mathematics, physics, and chemistry at the public library. At seventeen, he passed a high school equivalency examination through the University of London.

LIFE'S WORK

At nineteen, Emeagwali accepted a scholarship to Oregon State University to study mathematics. In a computer science course at Oregon, Emeagwali, given the job of programming computers, first conceived the theory that global weather prediction could be accomplished through harnessing thousands of small computers in a global network he called a "Hyperball international network of computers." His theory challenged traditional wisdom that held that no number of smaller processors could outperform a supercomputer. He was denied grants to pursue his theory and could find no research laboratory interested in it. He continued to work on his theory privately for fifteen years, immersing himself in physics, mathematics, and computing.

Awarded his bachelor's degree in 1977, Emeagwali went on to attend George Washington University, receiving a master's degree in civil engineering in 1981. He then attended the University of Maryland, receiving a master's degree in applied mathematics in 1986. That year, he was also awarded a post-master's degree in ocean, coastal, and marine engineering from George Washington University. After working for a time as a civil engineer in Maryland and Wyoming, Emeagwali entered the doctoral program of civil engineering at the University of Michigan to study scientific computing.

At Michigan, Emeagwali was part of a group reviewing the major problems that confronted science and engineering. Using a supercomputer to simulate oil reservoirs particularly interested Emeagwali, as he was from an oil-rich nation that could benefit greatly from advanced knowledge in that subject. At that time, extraction of oil relied on drilling through rock into an oil pocket, a process so inexact that it yielded at best only a small percentage of the oil. Moreover, the procedure could be completed only by using supercomputers (which could cost upwards of $30 million each) to simulate the oil reservoirs and chart an oil flow that could still become inaccessible.

Emeagwali applied his weather prediction theory to the petroleum reservoir problem and set about trying to solve one of the most difficult problems in the computing field by using his own technology. He was granted permission to use a supercomputer by the U.S. government, but it was withdrawn when the manager discovered that he was black. Emeagwali learned of the Connection Machine (comprising 65,536 microprocessors), built by a company called Thinking Machines for use with artificial intelligence, and was granted use of one at Los Alamos National Laboratory in New Mexico. Accessing the computer remotely from Ann Arbor, Michigan, he ran his program and was amazed when the microprocessors completed their tasks at record-breaking speed, computing the amount of oil in the simulated reservoir and tracking an oil flow underground. Various oil companies purchased supercomputers similar to the one he had used, and many sought his expertise in implementing them.

SIMULATING OIL RESERVOIRS

While wrestling with the problem of accessing underground oil for the petroleum industry, Philip Emeagwali determined to use a supercomputer equipped with thousands of microprocessors rather than use the extremely expensive vector supercomputer, whose calculations were performed from a long list of numbers and whose ability to communicate was limited. Emeagwali programmed a Connection Machine that was equipped with 65,536 microprocessors. The processors were arranged as more than four thousand computational nodes, each with a cluster of sixteen processors and eight information channels emanating from each processor.

Never relying on mathematics and computer science alone, Emeagwali included physics in his calculations, specifically the second law of motion formulated by English mathematician and physicist Sir Isaac Newton. Emeagwali rightfully assumed that Newton's law concerning force, mass, and acceleration applied to the fluids below the Earth's surface. He reformulated Newton's law into mathematical equations codifying the laws of motion to simulate oil reservoirs. His calculations also considered inertia, previously unaccounted for in the equations developed by other scientists and mathematicians. Using advanced calculus, Emeagwali constructed nine equations and nine corresponding algorithms (precise statements that allow the computer to solve the equations). The eighteen differential equations (reformulated as 24 million algebraic equations) were founded upon the four primary forces in oil fields—pressure, gravitation, acceleration (or inertia), and viscosity. In programming his computer, Emeagwali divided a huge imaginary oil field into 65,536 smaller oil fields, and he distributed the equations equally among the 65,536 microprocessors. The supercomputer performed 3.1 billion calculations per second, a record set in 1989.

In the petroleum industry, Emeagwali's oil reservoir simulation is regarded as an outstanding contribution to oil field science. Reservoir modeling provides the industry with the necessary knowledge to recover oil efficiently. The equations provide geologists with the knowledge of favorable conditions for the injection of water to increase the production of oil, and the inclusion of inertia in the equations gives an accurate reflection of the amount of available oil. Emeagwali's unconventional method of computing and reservoir simulation aids engineers in recovering the maximum amount of oil in a reservoir and has saved the petroleum industry millions of dollars per oil field.

Emeagwali submitted his doctoral thesis on his supercomputer experiment. However, it was not accepted, and his degree was not awarded. He challenged the decision by suing the university, alleging racial discrimination, but his lawsuit was dismissed. He returned to his research on weather prediction, using the supercomputer to predict weather, and to his Hyperball network. Following his success with the Connection Machine, he conceived of his network as a "World Wide Brain" that would take the World Wide Web to the next level.

Emeagwali married the former Dale Brown, a molecular biologist, and they settled in Washington, D.C., with their son. Both became active spokespersons for the accomplishments of nonwhites in science. In 1989, Emeagwali was awarded the Gordon Bell Prize, considered the Nobel Prize for computing, given to an individual or a group who has made significant achievements in using supercomputers to solve scientific and engineering problems. Achieving international fame, he received numerous awards, including the Distinguished Scientist Award from the National Society of Black Engineers (1991); Computer Scientist of the Year, given by the National Technical Association (1993); and Eminent Engineer, Tau Beta Pi National Engineering Honor Society (1994). He was praised by President Bill Clinton as "one of the great minds of the information age," and has been ranked as one of history's eminent black achievers. In Nigeria, he is a national hero.

IMPACT

Emeagwali's most significant achievement was his contribution to computer knowledge. He never intended to work on computers themselves, but was concerned only with the power of the knowledge that drove them. At Oregon State University, he disliked computers, feeling more comfortable with performing calculations in his head, but he soon realized their enormous capabilities and began to theorize a future for them that was deemed all but impossible by others. His accomplishment with the Connection Machine not only benefited the petroleum industry but also demonstrated the possibility of a high-speed, relatively low-cost method of global communication. His microprocessor technology was utilized by Apple in its Power Mac G4 series.

Emeagwali understood that one problem with computers was their inability to "talk to each other." In an age of specialization, he examined issues from a multidisciplinary approach, applying the laws of physics, mathematics, and computers to advance beyond the 1970's idea of the Internet as a network of thousands of interconnected computers to an Internet composed of millions of computers communicating with one another. He understood that computers had the capability to simulate planetary motion to reveal both past and future events, as well as the capability to solve mathematical equations to simulate both the big bang theory of the origin of the universe and nuclear explosions. Hailed by the Cable News Network (CNN) as the "father of the Internet," Emeagwali has advanced technology significantly by expanding the boundaries of computing.

—*Mary Hurd*

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See also: Tim Berners-Lee; Bob Kahn; Sir Isaac Newton; Alan Mathison Turing.

Great Lives from History

Inventors
& Inventions

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Volume 2
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JOHN ERICSSON

Swedish American mechanical engineer

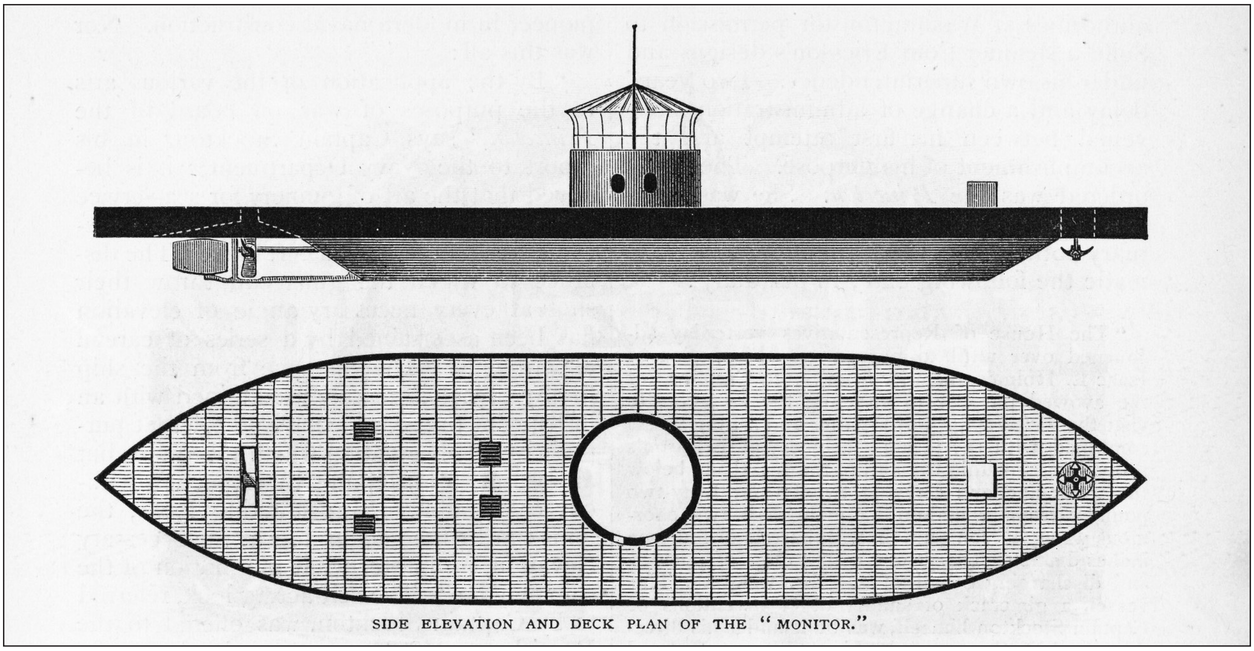
Though Ericsson demonstrated a genius for originating many mechanical devices, it was his work in naval weapons technology in the service of the United States during the Civil War that earned him his greatest renown. His most notable achievement was the ironclad Monitor, *which revolutionized maritime warfare and factored significantly in the ultimate victory of the United States over the Confederacy.*

Born: July 31, 1803; Långbanshyttan, Värmland, Sweden
Died: March 8, 1889; New York, New York
Primary fields: Military technology and weaponry; naval engineering
Primary inventions: Ironclad ship USS *Monitor*; hot-air engine

EARLY LIFE

John Ericsson (EHR-ihk-suhn) was born the youngest of three siblings, after his brother, Nils, and his sister, Anna Carolina, to Olof Ericsson and Brita Ingstrom. Ericsson, despite growing up in modest circumstances in Sweden, was exposed to advanced mathematical and engineering concepts at an early age. This was mainly due to the influence of his father, who worked as an explosives and topographical expert on the construction of the Göta Canal between Stockholm and Göteborg, and—prior to 1810—in the mining industry. John was also fortunate enough to come under the tutelage and patronage of Count Baltzar Bogislaus von Platen—admiral in the Swedish navy and director of the canal project.

By the time of his father's death in 1818 at the age of forty, Ericsson had already been at work for four years in engineering and surveying and had just secured a commission in the Swedish army. From 1817 to 1826, he was a member of a unit known as the Jämtland Field Ranger Regiment and was promoted to the rank of first lieutenant. Shortly before his retirement, he was granted a royal commission as captain. It was during his stint in the military that Ericsson first turned his hand to innovation: drawing up a design for a "hot-air engine," which he would work at refining for years. Wanting to launch an independent career, and aware that his native Sweden offered limited opportunities in this regard, Ericsson took a "leave of absence" and immigrated to Great Britain. He would later be pardoned for the charge of desertion by the Swedish government and allowed to resign officially from his military commission.



An engraving of the side elevation and deck plan of John Ericsson's USS Monitor. (Getty Images)

THE USS *MONITOR*

John Ericsson's ironclad warship the USS *Monitor* was labeled both affectionately and derisively as the "cheese box on a raft," "rat trap," and "tin can on a shingle." It was among the most unprepossessing, but significant, warships of the nineteenth century. The design for the famous Union ironclad was simplicity itself: a flat, shallow-draft deck with a small revolving gun turret in the center. Ericsson had conceived the original design for a warship with a "cupola" (revolving turret) in the early 1850's, and it was initially presented to Emperor Napoleon III of France. The Swedish inventor was, at that moment, aggrieved with the U.S. Department of the Navy over its failure to compensate him for his work on the USS *Princeton*. The French government never followed up on the scheme. Therefore, years later, in 1861, Ericsson—whose resentment over his past treatment had been somewhat mollified over time—submitted his cupola design to the Union Navy's special Ironclad Board and was awarded a contract on October 4, 1861. The inventor proposed the name "Monitor" in the hope that his vessel would serve as a "severe monitor" to the "leaders of the Southern Rebellion."

Completed, the USS *Monitor* took on a crew of sixty-three sailors and officers, the turret (the final version of which was refined by Theodore Timby) was fitted with two eleven-inch Dahlgren smoothbore cannons, and, under the command of Lieutenant John L. Worden, hurried south from New York to battle the Confederate ironclad CSS *Virginia* at Hampton Roads, Virginia, on March 9, 1862. The four-hour fight was a stalemate; the *Monitor* was faster and more maneuverable than its larger opponent, but the mechanical limitations involved in settling the revolution of its turret rendered its artillery's aim less accurate than that of the *Virginia*. At day's end, neither vessel was able to penetrate the other's armor.

There was to be no repeat of the Hampton Roads face-off: The *Monitor*'s role was to act as a defensive deterrent to the *Virginia*, keeping it bottled up in Portsmouth harbor. After the destruction of the *Virginia* by the retreating Confederates on May 11, 1862, the *Monitor* accompanied the Union fleet up the James River toward Richmond and engaged the Confederate batteries at Drewry's Bluff (Fort Darling) on May 15, 1862. The U.S. fleet lost the battle, and the *Monitor* proved to be ineffectual because it could not raise its own cannons to a high enough level to target the Confederate batteries on the bluff.

For most of the remainder of the year, the *Monitor* was stationed on uneventful patrol duty in the James River. On December 20, 1862, it journeyed southward to join the federal blockading fleet located off Charleston, South Carolina. Early in the morning on December 31, 1862, however, the ironclad sank during a squall off Cape Hatteras, North Carolina, with the loss of sixteen crewmen.

LIFE'S WORK

Ericsson's first true claim to fame occurred in 1829 as a result of his collaboration with already-notable British engineer and inventor John Braithwaite. Ericsson and Braithwaite combined their skills to built a steam locomotive that they dubbed *Novelty*. The engine would compete in the famous Rainhill Trials to determine which engine was to transport passengers and goods along the world's first railway—which ran from Manchester to Liverpool. Beginning on October 6, 1829, and pitted against four other engines, the *Novelty* outlasted all except the eventual winner, the *Rocket*, which was designed and operated by George and Robert Stephenson. Though initially attaining the fastest speed (twenty-eight miles per hour), the *Novelty* had to withdraw because of boiler problems.

Thereafter, Ericsson's sojourn in England was not a happy one: His failed marriage to an English girl, Amelia Byam, and bankruptcy resulting in a stay in debtors' prison were aggravated by the rejection of his steam fire engine, and of his double-screw propeller for powering ships. Dispirited, he immigrated once more, in 1839, this time to the United States. Captain Robert Field Stockton of the U.S. Navy had become intrigued with Ericsson's work and persuaded him to sail to New York, where Ericsson would establish his permanent residence and become a naturalized American citizen in 1848.

Under Stockton's sponsorship, Ericsson was commissioned to devise an advanced frigate to be powered by his double-screw propeller, and with the engine situated below water level so as to afford additional protection during combat. After some backstairs political maneuvering, at which Stockton excelled, the project was finally completed, in the form of the USS *Princeton*. It was built in 1843 during the John Tyler administration and placed under Stockton's command. This was the first such vessel built for the U.S. Navy and was further embellished by the pair of monster cannons that were mounted on deck. One of these, the "Oregon" (originally styled the "Orator" by Ericsson until Stockton changed its name) was the Swedish engineer's creation and based on the strengthening of the gun barrel by hoops. The other, the "Peacemaker," was based on a different design of Stockton's, who copied Ericsson's model—minus the hoops. On February 28, 1844, the Peacemaker exploded, firing a ceremonial round while cruising on the Potomac River, killing six, including Secretary of State Abel Upshur and Navy Secretary Thomas Gilmer, and injuring twenty, including Stockton.

During the courts of inquiry surrounding the Peacemaker incident, Stockton's considerable political clout enabled him to be officially exonerated, and to shift some of the blame on Ericsson. As a result of this rather blatant scapegoating, the Navy withheld Ericsson's payments. Angered and indignant, Ericsson refused to deal further with Stockton and the Navy Department and submitted ship and engine designs, including a prototype ironclad vessel, to Emperor Napoleon III of France. However, little came of this.

At the outbreak of the Civil War, Ericsson's bitterness at his treatment over the *Princeton* controversy led him first to refuse to work for the U.S. Navy. However, after the Confederates captured the Gosport Naval Yard at Portsmouth, Virginia, on April 20, 1861, they were able to salvage the hull of the warship USS *Merrimack* and transform it into an invulnerable ironclad vessel that they rechristened the CSS *Virginia*. Spy reports informed the Department of the Navy in Washington, D.C., and the federal authorities scrambled to react to this impending threat. They put together a special "Ironclad Board" to develop a vessel to counteract the *Virginia* before it could do irreparable damage. Ericsson submitted his design to the board on September 3, 1861. It was at first ruled out, but the individual who was awarded the contract, Cornelius Bushnell, had an engineering problem in his own ironclad design (Bushnell's design would later be realized in the warship USS *Galena*) and decided to consult Ericsson on the matter. While visiting Ericsson at his home, Bushnell was sufficiently struck by Ericsson's own designs, the same that had previously been presented to Napoleon III, to persuade Ericsson to allow him to present them first to Secretary of the Navy Gideon Welles and then to President Abraham Lincoln. Lincoln voiced his support and the following day, September 13, 1861, the Ironclad Board convened. After a personal presentation by Ericsson a day later, the design was endorsed. A contract worth $275,000 was drawn up for Ericsson on October 4. Laboring at a feverish pace, Ericsson and workmen at various factories and foundries completed the ship, which was named the USS *Monitor*, and which sailed on March 6, 1862, from New York to Virginia.

On March 8, during the first day of the Battle of Hampton Roads, the *Virginia* fell upon the wooden Union fleet, destroying the warships *Cumberland* and *Congress* and disabling the *Minnesota*. That night, the *Monitor* arrived at Hampton Roads and took up a position protecting the *Minnesota*. March 9 witnessed the fabled daylong duel between the *Virginia* and the *Monitor*, which culminated in a stalemate, neither ship being able to score a decisive advantage over the other. "Ericsson's Battery," as the *Monitor* was first known, became the prototype for a series of *Monitor*-style ships such as the *Weehawken*, *Montauk*, and *Tecumseh*. These factored in the eventual Union victory in 1865.

Ericsson's later inventions combined military and peacetime usage. It was during this latter part of his life that he returned to perfect one of his earliest innovations, the hot-air engine, which he had first devised while in the Swedish army. Ironically, it was to be this invention of his youth, which had first failed in England because it had to be adapted to coal rather than wood (which was at that time the standard fuel in Sweden), that, after Ericsson had tinkered and perfected the engine to operate on coal, would earn him the financial security that had eluded him for most of his life. Ericsson's third innovative warship was the *Destroyer*, designed in 1878. The *Destroyer* had the revolutionary capability of firing torpedoes underwater and would become the prototype for the powerful destroyer warships of the twentieth century. Ericsson continued working on various class warship designs throughout his life and developed a solar engine that could be powered by the Sun's energy.

Despite a controversial career highlighted by a considerable ego, which made him very sensitive to perceived slights, and a naturally combative disposition, Ericsson was well honored in his lifetime, gaining membership in the Royal Swedish Academy of Sciences and the Royal Swedish Academy of War Sciences. He authored two books, *Solar Investigations* (1875) and *Contributions to the Centennial Exhibition* (1876).

IMPACT

There is little doubt that Ericsson's genius helped to turn the tide of the American Civil War at one of its crucial junctures, and to render the traditional wooden navies totally obsolete. The comparative success of Ericsson's *Monitor*, insofar as it was able to neutralize the Confederate ironclads and, so, to maintain the pressure of the Union blockade, contributed greatly to the gradual weakening of the Confederacy. It was quite possibly the very irascibility in his temperament that spurred a dogged determination to persevere in the face of doubt and opposition until a solution was found—which sometimes rendered his designs so unconventional, and in the final analysis, so effective. Apart from the hot-air engine, the *Princeton*, the *Monitor*, and the *Destroyer*, his inventions—though in the main very revolutionary in conceptualization—had a less spectacular impact. However, the practical value of his steam condenser, which permitted seawater to be desalinated and made fresh during a sea voyage; the solar engine; and the self-propelled torpedo would hold notable implications for the future of maritime commerce and warfare. The hot-air and solar engines, in their potentially less environmentally wasteful applications, may be seen as a foreshadowing of the fuel-conservationist ideas of the twenty-first century.

—*Raymond Pierre Hylton*

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See also: Richard Gatling; George Stephenson; Robert Stirling.

Oliver Evans

American mechanical engineer

Evans's automated flour mill was the forerunner of continuous production lines, and his innovative high-pressure steam engine had multiple uses, the most important of which was powering steamboats on American rivers.

Born: September 13, 1755; near Newport, Delaware
Died: April 15, 1819; New York, New York
Primary fields: Food processing; manufacturing; mechanical engineering
Primary inventions: Automated flour mill; high-pressure steam engine

Early Life

Oliver Evans was born in New Castle County near the town of Newport, Delaware. He was the fifth child and fourth son of Charles Evans, a shoemaker who later became a farmer. Oliver's mother, Ann, was the daughter of a miller. He grew up in a large family of twelve children. After attending a country school, he was apprenticed, as a teenager, to a wheelwright. During the day, he learned how to make wagons, and at night he studied books on mechanics and mathematics by the light of flaming wood shavings. In what proved to be an epiphany, he learned how a blacksmith's son used steam in a gun barrel to propel wadding with great force. This led Evans to study the Newcomen and Watt steam engines and to speculate about the possibilities of a steam-powered carriage.

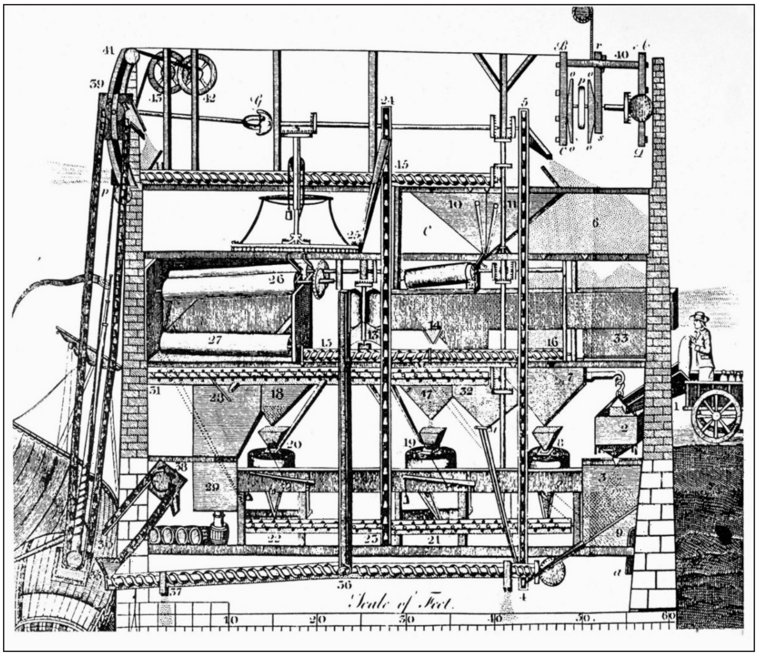
During the Revolutionary War, he joined a Delaware militia company, but his unit was never called into active service. This war for independence from Great Britain created a shortage of wool-combing cards, needed for making homespun cloth. These leather-bound wooden devices had wire teeth for cleaning and straightening fibers used in making thread or yarn, but American blacksmiths had no efficient way of manufacturing the wire teeth. Evans invented a machine that created the teeth and set them into combs. His machine had the capacity to make 1,000 to 1,500 cards per minute. His invention was a great success, but, to his dismay, he discovered it was widely pirated, and he received little reward for his hard work.

LIFE'S WORK

After the war, in the early 1780's, Evans's business career began when he and a younger brother moved to Maryland, where they opened a store. Because of the store's success, Evans was able to marry Sarah Tomlinson, a yeoman farmer's daughter, at a Wilmington Episcopal church. He brought her back to Maryland, where, from his dealings with millers, he became interested in gristmills. After learning of these mills' inadequacies, he began to think of ways in which technology could be used to improve the production of flour, and he designed models for a new kind of flour mill involving many new inventions. He later purchased an old mill, which became the focus of transforming his ideas into realities.

By 1785, Evans had created a completely automated flour mill whose various mechanical devices ran on waterpower. He used such grain-handling and grain-processing devices as elevators, millstones, descenders, and Archimedean screws to move and process grain, meal, and flour efficiently from place to place and from machine to machine. A particularly innovative device was the hopper-boy, so called because it replaced the tasks that young workers had previously performed. A twelve-foot-long revolving rake spread flour evenly on the floor, where it dried and cooled. The product of this process was then mechanically guided to a hopper, a funnel-shaped receptacle, and gravity then directed a stream of falling flour into a bolter, a fine-meshed cloth that separated the fine, clean flour from the chaff. Laborers then packed the flour into barrels, ready for shipment and sale. Basically, Evans had created a continuous manufacturing process that transformed grain into flour with little human intervention.

In 1786, Evans petitioned the legislatures of such states as Delaware, Maryland, and Pennsylvania for a fifteen-year exclusive monopoly on his automated flour mill, and the state legislatures responded favorably. In 1790, when the federal patent system became law, Evans received the third U.S. patent issued, for his improvements in milling. In 1793, he moved to Philadelphia, an important commercial center, where he set up a shop for selling millstones, bolting cloths, and licenses for constructing his automated flour mill. During the next decade, he licensed his inventions to more than a hundred clients, including such distinguished Americans as George Washington and Thomas Jefferson. In 1795, he published *The Young Mill-wright and Miller's Guide*, which proved to be extraordinarily influential both in the



Oliver Evans's automated flour mill, the first of its kind, used bucket chains and Archimedean screws and required little human intervention. (The Granger Collection, New York)

United States and Europe, passing through fifteen editions between 1795 and 1860. It also facilitated the pirating of his inventions: During the period of his patent, he encountered many problems in collecting royalties from various millers.

During the late eighteenth and early nineteenth centuries, Evans had been fascinated with steam engines. He came to believe that the large, low-pressure Newcomen and Watt engines would be inadequate for propelling water and land vehicles, and he devoted himself to developing a light, high-pressure steam engine. In 1801, he constructed such an engine that powered a device that pulverized limestone to provide fertilizer for farmers. Over the next few years, he improved his invention, which, unlike the Watt engine, had no condenser and situated the cylinder and the crankshaft at the same end of the beam. To solve the problem of maintaining the vertical motion of the piston in the steam cylinder, Evans cleverly created a connection between the working beam and pivoted bars, which came to be known throughout the world as the Evans straight-line linkage. In 1804, he received a U.S. patent for what he later patriotically called the Columbian steam engine. Since his engines were cheaper to construct, easier to operate and maintain, and more compact, versatile, and portable than the Watt engines, they quickly replaced these engines for powering mills that sawed lumber and ground grains. Most important, the Columbian steam engines propelled most of the steamboats on the great rivers of America.

The Philadelphia Board of Health, concerned about sandbars and pollution in the Schuylkill and Delaware rivers, commissioned Evans to build a steam-powered dredge. In 1805, his gigantic contraption, christened the Orukter Amphibolos, or Amphibious Digger, moved on wheels through the streets of Philadelphia, thus becoming America's first steam-powered land vehicle. When it was launched into the river, it became America's first amphibious vehicle. Despite Evans's later claims, the Orukter Amphibolos was not very successful as a dredge, and it was later decommissioned and disassembled for parts.

During this time, Evans experienced other frustrations, as he battled in vain against infringers on his patents and against government officials who refused to extend his patents. He vented his spleen in *The Abortion of the Young Steam Engineer's Guide* (1805), in which he explained his side of the controversy with John Stevens over principles involved in the making and operation of steamboats. He also described his improved high-pressure steam engine as well as some of his other inventions, such as a screw mill for grinding plaster of paris.

In 1806, Evans created the Mars Works, which eventually contained a foundry, a blacksmith's shop, a factory that made patented grindstones, and a steam-engine workshop. Over the next decade, his workers made fifty to one hundred steam engines that were adapted for various applications, from powering screw presses in the processing of cotton and tobacco, to pumping water out of mines. He also had many orders for

The Automated Flour Mill

Motivated by the need to invent machines to replace expensive manual laborers in the grain-to-flour business, Oliver Evans developed an integrated system of mechanical devices and processes that produced a superior flour with minimal human input. Initially, waterwheels supplied the power; humans were necessary only to start and monitor the machines and barrel the flour. Examples of Evans's mechanizations include an endless belt-and-buckets device that delivered the grain to an upper floor at a rate of three hundred bushels per hour. The buckets emptied the grain into a hopper above the millstones, and gravity guided the grain to these rotating millstones, where the grain was ground into flour. An elevator then carried the moist, warm flour to an upper floor, where a hopper-boy, after the crude flour was spread, cooled, and dried, separated the bran and dirt from the flour. Though the elevator and hopper-boy were pivotal machines in Evans's system, he also made important use of descenders, endless belts by which processed material could be conveyed, at an angle, downward, and Archimedean screw conveyors whereby meal was transported from one mechanical processor to another. In sum, Evans was able, by the clever use of water-powered machines and gravity, to take grain through the stages of grinding, drying, cooling, and sorting without human intervention.

Many scholars view the automated flour mill as Evans's greatest contribution because it was an important first step in transforming the American economy from subsistence to efficient mechanized agricultural production. It was also significant because it embodied, for the first time, the new and revolutionary idea of a continuous manufacturing process. His later use of steam power to run his flour mills liberated them from locations with swiftly flowing water. The fact that his flour mill innovations were so often pirated is also an indication of their importance: They were well worth stealing. Evans certainly created other great inventions, but it was largely his automated flour mill that was responsible for his status as a founding father of American technology.

steamboat engines; during the War of 1812, he offered to make a steam-powered warship for the U.S. Navy, but his offer was not accepted. He also experienced a more violent rejection when, in 1813, he raised the cost of license fees for millers who used his flour-milling system. Millers in Baltimore revolted, and this contention became the subject of a congressional committee investigation, which ultimately sided with Evans.

By his sixties, the many years of business turmoil and legal battles had eroded Evans's energy. Nevertheless, he remained active, and in 1815 he published a paper comparing high- and low-pressure steam engines. In 1816, he lost his beloved wife, Sarah, and his failing eyesight and other health problems interfered with his attention to inventing and his businesses. Though the steamboat *Oliver Evans* was launched in 1817, it was later taken over by a group of Pittsburgh merchants, who renamed it the *Constitution*. In 1818, Evans married Hetty Ward, and over the next year he altered his will so that his young wife would be well provided for. Ward came from New York, and her husband was stricken with a lung inflammation while in New York City. His final illness was exacerbated by a destructive fire at the Mars Works. After his death on April 15, 1819, his businesses suffered, though his widow continued the campaign over the importance of his patents, businesses, and legacy.

Impact

Evans was the most accomplished and productive American inventor of his time. Two of his inventions—the automated flour mill and the high-pressure steam engine—had great influence on the Industrial Revolution in the United States as well as in several European countries. By 1837, more than one thousand automated mills existed in the states of the American West, and even more proliferated throughout the eastern states. Some modern scholars have argued that, over a century before Henry Ford's famous system for the mass production of automobiles, Evans had created, in his automated flour mill, the prototype of these later continuous mass-production techniques. When his flour-milling system spread to Europe, the French called it the "American system." The Germans, too, acknowledged Evans as a great innovator, though the British millers, while appropriating his ideas, largely ignored what others called the "first example of a truly revolutionary invention creditable to 'Yankee ingenuity.'"

The high-pressure steam engine that Evans developed became the model for most steam engines that powered factories, locomotives, and steamboats during the American Industrial Revolution. Though viewed as a glorious failure by some, his Orukter Amphibolos anticipated the automobile and amphibious vehicles. His ideas on solar energy and cogeneration were foreglimpses of later significant technologies. He also assiduously battled for patent protection, helping to foster a new attitude that patent rights were significant ways for individuals, companies, and the country itself to progress both technologically and ethically. In recognition of his many important contributions, Evans was inducted into the National Inventors Hall of Fame in 2001.

—*Robert J. Paradowski*

Further Reading

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See also: Archimedes; Henry Ford; Thomas Newcomen; John Stevens; James Watt.

TONY FADELL

American software engineer

Fadell's idea of combining a portable hard drive-based MP3 player with an Internet-based electronic music catalog was realized with his invention of the iPod. The iPod revolutionized the way consumers purchase and listen to music and led to the development of the iPhone, which has revolutionized cell phone technology in its own right.

Born: 1969; Detroit, Michigan
Also known as: Anthony Michael Fadell (full name)
Primary fields: Computer science; electronics and electrical engineering
Primary invention: iPod

EARLY LIFE

Anthony Michael Fadell was born and raised in Detroit, Michigan. In 1987, Fadell graduated from Grosse Pointe South High School in Grosse Pointe Farms, Michigan, and then went on to receive a B.S. in computer engineering from the University of Michigan in 1991. During his time at Michigan, Fadell was an active member of the Psi Upsilon Fraternity, in addition to holding the position of chief executive officer (CEO) at Constructive Instruments, which marketed MediaText, multimedia composition software for children.

In 1992, Fadell was hired by the Apple Computer spin-off General Magic, where he worked with former Apple Macintosh developers Andy Hertzfeld and Bill Atkinson until 1995. As a systems architect for General Magic, Fadell helped to develop a number of successful new portable computing technologies and devices, including the Sony Magic Link and Motorola Envoy. Also during this time, Fadell worked on a General Magic handheld communication device, which was a flop with consumers. In 1995, he was hired by Philips, where he became a cofounder, the chief technology officer, and the director of engineering in the Mobile Computing Group. Because of his young age, Fadell's position at Philips was viewed as controversial, an opinion that was validated by his cavalier attitude and nontraditional appearance in a conservative field. While at Philips, Fadell's Mobile Computing Group developed a number of Microsoft Windows-based handheld personal computers (PCs), notably the Velo and Nino. Through his work on these handheld devices, Fadell began to realize the importance of digital audio and the MP3 format, particularly in handheld and portable devices. Fadell later served as vice president of business development (1998-1999). During this time, he was in charge of developing Philips' Internet and digital audio strategy and investment portfolio.

Fadell eventually started his own company, Fuse, in order to develop a hard drive-based jukebox-style music player capable of storing thousands of songs that was small enough to fit in one's hand. Funding for this project proved to be difficult, and Fadell was forced to explore developing the product at other companies. Fadell accepted a job at RealNetworks in 2000 to develop the software for his project but only remained with the company for six weeks due to creative differences. Fadell next approached Apple with his idea, and he was hired to develop an easy-to-use MP3 player that was compatible with the existing iTunes software.

iPod
Playlists
Browse
Extras
Settings
Backlight
MENU

The original Apple iPod, a hugely popular portable media player, was released in 2001. (AP/Wide World Photos)

Life's Work

During the late 1980's and early 1990's, the music industry had made significant changes, including a switch from analog to digital content. With the advent of the compact disc (CD), analog music became increasingly obsolete, leaving consumers and electronics manufacturers hungry for a convenient and portable music player that could capitalize on the benefits of digital music. In the mid-1990's, software and hardware engineers were working to capture the public's interest in the Internet as well as developing handheld data devices. One such engineer was Fadell, who envisioned a portable handheld hard drive-based MP3 player to be used in conjunction with a Web-based music store.

Commonly known as the "father of the iPod," Fadell was originally hired by Apple in February, 2001, as the first member of the iPod engineering team. Initially hired as a contractor to assist in the design of the iPod, Fadell also aided in planning Apple's overall audio product strategy, which came to include the iTunes Store. The key to the development of the iPod was a tiny hard drive manufactured by Toshiba that, despite its 1.8-inch size, held 5 gigabytes of data, capable of storing up to one thousand songs. With the addition of the newly developed high-speed FireWire technology, the iPod prototype finally took shape. The device would be small enough to fit in a pocket, have enough space to hold up to a thousand songs, and have the ability to interface with iTunes to load a large number of songs quickly and conveniently. The iPod was developed in less than six months, faster than any major product in the company's history.

In the years prior to the release of the iPod and its accompanying iTunes software, Internet users illegally downloaded music from Web-based file-sharing services, the most notorious of which was Napster. As a result, the music industry was experiencing a crisis from lack of revenue and was aggressively seeking redress from the legal system. Without precedent or the technology to identify those illegally downloading music, the legal system was slow to address the problem, which seemed to have no easy solution. In fact, one highly effective solution came in the form of the iPod. By creating a relatively inexpensive device that was capable of downloading and playing back digital music in conjunction with the development of the iTunes Store, where more than 200,000 digital songs were available for download for a dollar each, Apple presented consumers with a legal alternative to file sharing. Both the iPod and the iTunes Store were hugely successful with consumers as well as lauded for their technological ingenuity by the computer engineering community.

After his initial contract expired, Fadell was hired again by Apple in April, 2001, this time to assemble and run its iPod and Special Projects Group, in which he was responsible for overseeing the design and production of the iPod and iSight (Webcam) devices, following the direction of Jon Rubenstein.

In 2004, Fadell was promoted to vice president of iPod engineering, a position he held until 2006. On October 14, 2005, Apple announced that Rubenstein was retiring from his position as senior vice president of the

The iPod

The iPod is a portable media player designed by Apple for the storage and playback of audio files encoded by MP3 (MPEG-1 Audio Layer 3) or AAC (Advanced Audio Coding) compression algorithms. Originally developed by Dolby Labs as part of the MPEG-4 audio/video standard, AAC differs from MP3 in its ability to support digital rights management (DRM). DRM was developed as a solution to the problems that arose from file-sharing Web sites and music piracy by encoding legally purchased songs with digital signatures, thus increasing the difficulty of sharing them illegally.

iPods are similar to handheld jukeboxes in that they can hold anywhere from a few hundred to thousands of songs for playback, depending on the storage size of the model. Today, some iPods allow video playback and video game play with touch-screen technology in addition to music applications. iPods typically use one of two types of storage: miniature hard drives or flash memory. Miniature hard drives can measure fewer than two inches and can accommodate more than 100 gigabytes of data for audio or video storage. On smaller units, flash memory is used in place of a hard drive and is typically capable of storing up to 8 to 16 gigabytes of data.

The iPod continued Apple's tradition of creating state-of-the-art technology that consumers are able to use easily and efficiently. When connected to a personal computer, the iPod interfaces with the iTunes software and automatically synchronizes the songs available on the iPod with those available on the computer without prompting from the user. FireWire technology allows for the rapid loading of songs onto the iPod, which is essential given the vast storage capacity currently available. The iPod dominated the portable MP3 player market from its inception, largely due to its ease of use.

iPod Division on March 31, 2006, and Fadell would be stepping in as his replacement. During his time with the iPod, iSight, and Special Projects Group, both the iPod and iTunes underwent several technological advances, including the hugely popular click-wheel navigation interface developed by Phil Schiller, the addition of a color touch screen, and the licensing of videos, movies, and television programs for purchase at the iTunes Store. Fadell created three generations of the iPod and the iSight. In addition, the hard drive technology used to create the iPod was incorporated into the development of the iPhone, which boasts the features of an 8- or 16-gigabyte iPod Touch as well as those of a cellular phone, a portable Internet device, and a digital camera.

On November 4, 2008, Apple announced that Fadell was stepping down as senior vice president but would remain with the company as an adviser to CEO Steve Jobs. Over his lifetime to date, Fadell has filed more than twenty patents for his work.

IMPACT

Fadell is a dynamic inventor who saw the possibilities of a portable MP3 player designed to communicate with both music software and an Internet music store. Fadell's development of the iPod in conjunction with the iTunes Store was a brilliant solution that helped to slow the flow of illegal file sharing between music fans that had plagued the music industry since the inception of the Internet. Consumers were able to select from hundreds of thousands of songs and legally download them at an affordable price. Both the iPod and iTunes were phenomenally successful from both a financial and a technological perspective. Through continued developments, such as the addition of a touch screen and video capability, the iPod has become a global technology that has been imported to mobile phones and other handheld devices.

—*Sally A. Lasko*

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See also: Steve Jobs; Steve Wozniak.

FEDERICO FAGGIN

Italian American electrical engineer and physicist

Faggin was head of the teams at Intel that developed the 4004, 8008, and 8080 microprocessors, and he cofounded the companies that invented the Z80 microprocessor and the leading touch pad for laptops.

Born: December 1, 1941; Vicenza, Italy
Primary fields: Computer science; electronics and electrical engineering; manufacturing
Primary invention: Intel microprocessors

EARLY LIFE

Federico Faggin (FAH-jeen) was born in Vicenza, Italy, in 1941. His father, Giuseppe, taught general history and the history of philosophy. Federico disappointed his father and his mother, Emma, when he showed a preference for technical subjects and mechanical devices over the humanities. For instance, he built his own model airplane when he was eleven years old.

After graduating from A. Rossi, a technical high school in his hometown, in 1960, Faggin took a job with

Olivetti in Borgolombargo (near Milan) as a technician. After two months of training in transistors and digital electronics, he was assigned to finish a project to design and build a small (by the standards of the time) computer. It took him about a year. When the machine was finished, it was seven feet tall, was as wide as a door, contained several hundred circuit boards, and had a memory capacity of 4,000 bytes. About ten years later, Faggin duplicated the functions and capacity of his Olivetti computer on a single computer chip and later on just a small spot of a chip. Faggin returned to school in 1961 and earned a doctorate in solid-state physics from the University of Padua in 1965. After teaching physics for a year, he went to work for the transistor manufacturer SGS, which was partly owned by Fairchild Semiconductor, and worked on metal-oxide-semiconductor (MOS) technology.

Faggin married Alvia, a technical writer, in 1967. They had three children: Marzia, an artist; and Eric and Marc, both scientists.

LIFE'S WORK

In 1968, Faggin left his pregnant wife in Italy to work in the Fairchild Semiconductor Laboratory in Palo Alto, California. He was only supposed to stay for six months, but he eventually brought his family over. At Fairchild, Faggin created the silicon-gate process for the Fairchild 3708 integrated circuit. Prior to this time, all transistors had to be connected to an aluminum wire, called a metal gate. This limited the number of transistors that could be placed on a single chip to a few hundred. Faggin devised a method to make wires out of polysilicon and to align them automatically, allowing thousands of transistors to be placed on a single chip. The polysilicon gates were also faster, used less energy, were cheaper to manufacturer, and took up less space.

Faggin joined Intel Corporation in 1970 and became leader of the project to build a single-chip central processing unit (CPU), eventually named the 4004, for a Japanese calculator manufacturer. One of his innovations was to create a methodology for random-logic chip design using silicon-gate technology, which he had already invented at Fairchild, and he made other innovations, enabling Intel to fulfill its contract. The design methodology created by Faggin was later utilized for the development of all Intel's early microprocessors. The 8008 development

THE INTEL 4004 MICROPROCESSOR

In 1969, the Japanese corporation Busicom (formerly Nippon Calculating Machine Corporation) approached Intel to produce twelve computer chips for its 141-PF printing calculator. However, Intel was still a small company at the time and did not have the resources to produce twelve different chips. Therefore, Intel engineers Marcian Edward "Ted" Hoff, Jr., and Stanley Mazor counterproposed a four-chip design in which one of the chips, which was eventually designated the 4004, was to be the central processing unit (CPU). (The "4" in the name indicated that it could process four bits of data at a time.) If successful, the cost of the calculator would be lower than the twelve-chip design and therefore be available to a wider market. However, at that time, no one in the semiconductor industry had ever produced a commercially viable single-chip CPU. In December, 1969, the companies signed an agreement in which they agreed on the architecture and which required Intel to create the prototypes by June, 1970. Busicom then paid Intel $60,000 toward development costs. However by April, 1970, little had been done on the 4004 except for a few diagrams.

Federico Faggin took over the project the very first day he started working for Intel. First, he received permission to move the deadline back to January, 1971. Then he developed the design methodology for random-logic circuits using the silicon-gate technology he had already developed at Fairchild Semiconductor. His method combined logic and circuit building blocks, including some novel circuits, with layout information, to make the design faster and less error-prone. Faggin made two additional innovations: buried contacts and bootstrap loads. The first innovation allowed him to make direct contact between polysilicon and junctions without having to use metal. The second was a trick widely used with metal-oxide-semiconductor (MOS) circuits but never with silicon-gate ones. Bootstrap loads allowed Faggin to build logic gates with output voltage equal to the supply voltage, simplifying the design by allowing him to use fewer transistors for particular functions.

Unfortunately, Faggin missed his January deadline, but he was finally able to ship samples of the chip to Japan in March, 1971. When he was finished with the prototype, Faggin put his initials on the chip, like a painter signing a canvas. The 4004 measured 3 by 4 millimeters, consisted of 2,300 transistors, and could perform 60,000 operations per second. Nippon eventually sold 100,000 of the calculators using the 4004 chip. In return for a refund of the money Nippon had paid for development, Intel retained the right to sell the chip to other manufacturers, so long as they were not in the calculator business. In November, 1971, *Electronic News* announced the chip's arrival as the first general-purpose microprocessor on the market.

was already under way in March, 1970, but was suspended until the 4004 was completed. Development resumed in January, 1971, under Faggin's direction. Completed in 1972, it was used in display terminals built by the Computer Terminal Corporation. Faggin then developed the architecture and led the development of the 8080 microprocessor, completed in 1974. It was used in the first generation of word processors made by Wang Laboratories and in the Altair 8800, usually cited by technology historians as the first personal computer. Sold as a kit through the mail in 1975, it ran software written by Microsoft founders Bill Gates and Paul Allen.

Faggin was unhappy with the management practices at Intel and left at the end of 1974 to start his own company. By the time he left, Faggin was head of research and development for semiconductors, supervised more than eighty engineers, and had developed more than twenty-five integrated circuits.

Intel was then primarily dedicated to making memory chips with microprocessors as a sideline. Zilog, the company Faggin cofounded with $1.5 million in seed money from Exxon, was the first company dedicated exclusively to manufacturing microprocessors. At his new company, Faggin designed the architecture of the Z80 microprocessor, which was finished in 1976. Tandy Radio Shack chose the Z80 for its TRS-80 home computer, and Wang used the microprocessor in its second-generation word processors, but its main success came from its installation in cars, toys, and appliances. Unfortunately, Zilog lost focus and chose to diversify into memory chips rather than concentrate on the successor to the Z80, the Z8000, which was not as successful. Unlike the Intel microprocessors, the Z8000 was not "backward compatible"—that is, it could not run software written for the Z80. Faggin was Zilog's president and chief executive officer (CEO) until the end of 1980, when Exxon completely acquired the company. Faggin sold his shares of Zilog for $4 million and rejoined the company as a member of the board in 2002.

In 1982, he cofounded Cygnet Technologies, maker of voice and data peripherals for personal computers, and was president and CEO of the company until 1986, when he and his partners sold the company to Everex. Later that year, he cofounded and became CEO of Synaptics. Its original purpose was to use neural networks to develop speech and pattern recognition technology, and it now produces the most widely used touch pad for laptop computers, a scrolling wheel for the iPod Mini, interface devices for MP3 players, and Chinese handwriting recognition devices. In 1997, Synaptics and National Semiconductor started Foveon, a joint venture to create imaging chips for digital cameras and later cell phones. Faggin stepped down as CEO of Synaptics in 1999 and from its board in 2008, but he became CEO of Foveon in 2003. He also serves on the boards of Integrated Device Technologies, which makes integrated circuits; GlobeSpan, which makes digital subscriber line (DSL) circuits; and Avanex, which makes fiber-optic products.

IMPACT

Even if Faggin had stopped innovating after his success at Fairchild, he would still be remembered as an important inventor. His silicon-gate technology is used in 90 percent of all semiconductors, which are now found in many devices besides computers, such as televisions, machine tools, traffic lights, medical instruments, and cell phones.

Although technology historians disagree over who was the "inventor" of the microprocessor, Faggin, because of his work at Intel and Zilog, has as strong a claim to that designation as anyone. The Intel 4004 microprocessor was used in an Apollo spacecraft that went to the Moon and had as much computing power as the Electronic Numerical Integrator and Computer (ENIAC), the first electronic computer, which filled an entire room and contained eighteen thousand vacuum tubes. The 4004, the 8008, and the 8080 are the ancestors of the microprocessors for personal computers that ran Microsoft's Disk Operating System, also known as MS-DOS or PC-DOS, and now run Microsoft Windows. Although Zilog's Z80 microprocessor was not ultimately successful as a CPU for personal computers, it was exceptionally successful as the heart of the electronics in more than a billion automobiles, toys, and appliances in the twenty years after its invention. This and other microprocessors made the personal computer technologically feasible and economically affordable.

Touch pads made by Synaptics are used in most portable computers as an alternative to mouses and trackballs. Since its introduction in 1994, the company has sold 125 million of them and has expanded their utilization to include MP3 players, cell phones, and personal digital assistants.

—*Thomas R. Feller*

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See also: John Presper Eckert; Bill Gates; Ted Hoff; Jack St. Clair Kilby; Robert Norton Noyce; William Shockley; An Wang.

DANIEL GABRIEL FAHRENHEIT

German physicist

Fahrenheit, a German instrument maker and physicist, developed the alcohol thermometer in 1709 and the mercury thermometer in 1714. He also devised the first widely used scale for measuring temperature, in which water freezes at 32° and boils at 212°, which today has been largely superseded by the Celsius scale in nearly all the world except the United States.

Born: May 24, 1686; Gdańsk (now in Poland)
Died: September 16, 1736; The Hague, Dutch Republic (now in the Netherlands)
Primary field: Physics
Primary inventions: Mercury thermometer; alcohol thermometer

EARLY LIFE

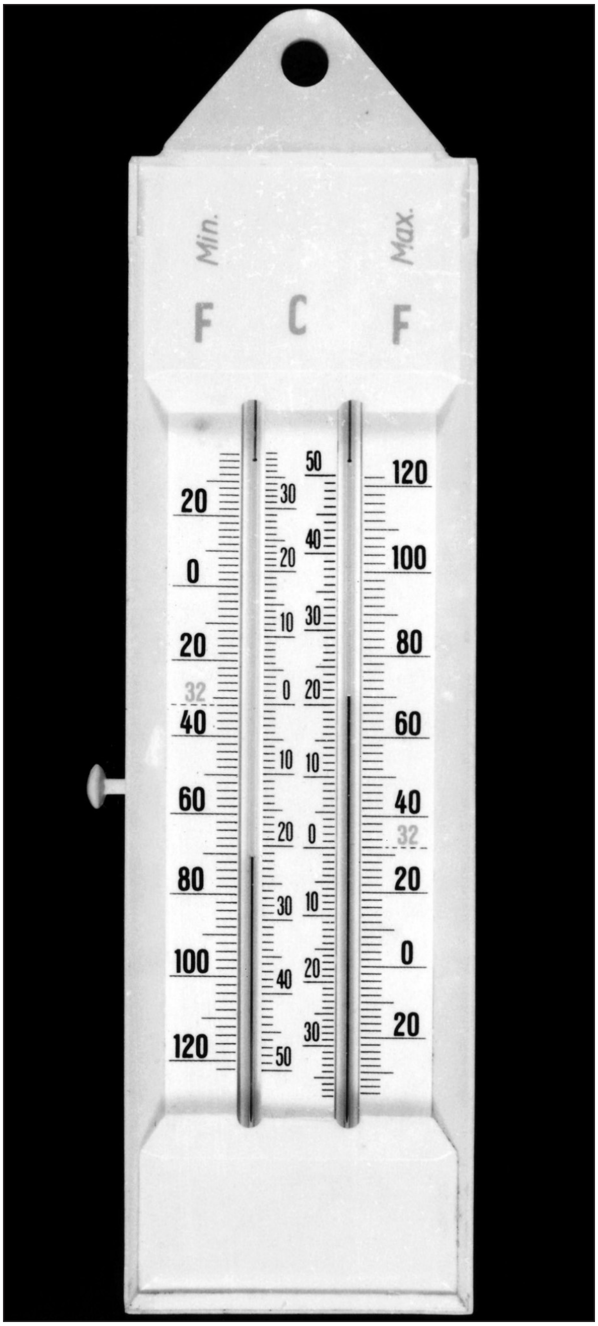
Born in Gdańsk (now in Poland) on May 24, 1686, Daniel Gabriel Fahrenheit (FEHR-uhn-hit) was the son of a prosperous trader, part of a line of merchants, some of them quite wealthy, stretching back several generations. His mother, Concordia, was the daughter of another prosperous Gdańsk business family, Schumann. Daniel was the eldest of two sons and three daughters born to the Fahrenheits. As a young man, he traveled with his family between cities in the Hanseatic League as his father plied his trade, with Gdańsk as their home. His grandfather, Reinhold Friedrich Fahrenheit, had established the family's reputation in Gdańsk as he became one of richest men in Prussia by trading.

At the age of fifteen, Fahrenheit lost both parents on the same day, August 14, 1701, after they accidentally ingested poisonous mushrooms. Thereafter, until age nineteen, he was lodged with an Amsterdam shopkeeper to be apprenticed as a merchant. The young man's interest in shopkeeping soon waned, however, and he began to display an avid interest in the natural sciences. He began to study physics, initiating a lifelong career as an instrument maker and glassblower.

Fahrenheit traveled widely throughout his life and spent considerable time in England**.** After 1707, he traveled to several cities, including Halle, Berlin, Dresden, Leipzig, Dresden, Copenhagen, and Gdańsk.

LIFE'S WORK

By the age of twenty-five, Fahrenheit was establishing himself as the leader in a continentwide competition to invent and calibrate the world's first accurate thermometer, as well as the first standard scale to measure changes in temperature, a matter of vital importance to the growing world of science. He spent most of his professional life in the Netherlands, where he developed the world's most precise instruments to measure temperature. He also studied physics and established that water may remain liquid below its usual freezing point (32° on his scale) and that the boiling point of liquids (most notably water) varies with atmospheric pressure.



A modern thermometer calibrated in Fahrenheit and Celsius. (The Granger Collection, New York)

Fahrenheit proved to be a meticulous scientist as well as a brilliant instrument maker. First, he studied previous attempts to manufacture a reliable thermometer as early as those of Galileo (1592) and as recent to his time as Guillaume Amontons (1699), a French physicist and instrument inventor, deducing that the accuracy of their instruments was limited by the fact that their thermometers were exposed to the air, which distorted measurement of air temperature with the varying influence of air pressure. He also studied the work of Ferdinando II de' Medici, who invented a closed thermometer in 1654.

Next, Fahrenheit turned to problems experienced during previous efforts to find a medium of measurement, usually water, alcohol, or both. Both water and alcohol produced vapors that distorted temperature readings, which varied with air pressure, even in a closed thermometer. In essence, a water-based thermometer functions also as a barometer, a device that measures air pressure. Water also did not expand or contract evenly enough to provide accurate readings as temperatures rose and fell. In addition, alcohol boiled at too low a temperature to make it a useful medium.

Fahrenheit was the first person to consider mercury as the best liquid to measure temperature in a closed thermometer. It expands and contracts evenly, freezes at a very low temperature (–78° on his scale, or –38.72° Celsius), and boils at a temperature that is relatively high (about 600° on his scale, or 357° Celsius). Mercury also produces very little vapor. Fahrenheit built closed-bulb devices using alcohol (1709) and mercury (1714). Mercury became the preferred medium despite its toxicity, and Fahrenheit's thermometers were state-of-the-art. He introduced cylindrical bulbs to replace spherical ones. Many of his methods were withheld as trade secrets for several years after he began to use them.

A number of stories have described how Fahrenheit devised his temperature scale, many of which are probably false. One says that he set zero as the coldest he observed in Gdańsk. This is probably not true because most of Fahrenheit's work was done in the Netherlands. Other stories say that Fahrenheit based his freezing point for water on the 32 degrees of enlightenment of the Freemasons. There is no evidence, however, that he practiced Freemasonry. Another story, also without documentary support, states that he believed a person would die of exposure to cold at 0 degree and of heatstroke at 100°.

Fahrenheit also invented a constant-weight hydrometer of excellent design and a "thermobarometer" that could estimate barometric pressure from the boiling point of water. Fahrenheit observed phenomena as a scientist that many people today take for granted, such as the fact that a pure liquid boils at a fixed temperature, regardless of how much heat is applied beyond that point.

After 1717, Fahrenheit established a glassblowing shop in The Hague, where he manufactured barometers, altimeters, and thermometers. After 1718, he delivered chemistry lectures in Amsterdam. He was inducted into the Royal Society during a visit to London in 1724. Fahrenheit never married, and he died on September 16, 1736, at the age of fifty, of an unknown cause, probably in The Hague. He was buried there at the Kloosterkerk (Cloister Church).

FAHRENHEIT'S THERMOMETER

Daniel Gabriel Fahrenheit's instruments were the first reliable thermometers. Fahrenheit completed his alcohol and mercury thermometers by carefully crafting several instruments to identical specifications and testing them until they calibrated temperature equally. He tried many different scales before settling on the one that would bear his name, using work by Guillaume Amontons to determine the boiling points of water and other liquids. He also discovered that mercury was an ideal liquid for measuring temperature.

Fahrenheit originally established 30° as the freezing point of fresh water and 100° as the normal human body temperature. His first estimate of body temperature at 100° became a landmark number on the scale, but his attempt to establish body temperature as a round number failed many tests, so he had to adjust it, first to 96°, obtained when he placed one of his thermometers under his arm and tongue. The Fahrenheit scale later was set to have 180° between the freezing point (32°) and the boiling point (212°) of water. This revised scale raised normal body temperature from 96° to 98.6°. Describing how he calibrated his scale from 0 to 212 in the *Philosophical Transactions of the Royal Society*, Fahrenheit wrote that zero was the coldest temperate at which the mixture of ice, water, and the salt ammonium chloride retained any trace of liquidity.

Fahrenheit's experiments also led to the discovery of ways to "supercool" water, which allows water to retain its liquid state below its usual freezing point. Fahrenheit's discovery of supercooling led him to believe that freezing and boiling points were not absolutes and that external conditions could cause them to move higher or lower than the fixed points at which he had calibrated his temperature scale.

IMPACT

Observation and measurement are key to the scientific method, and measurement with meaning is impossible without precise instruments. Science must be reproducible, and this is not possible without precisely measuring phenomena on a common scale, in a form that can be widely shared across languages and cultures. Fahrenheit's thermometers were invented at a time when scientists used several competing scales and instruments to measure temperature. By setting a worldwide scale and inventing instruments that calibrated it, Fahrenheit refined science in a fundamental way. Much of climate science, for example, would be impossible without accurate measurement of temperatures. Other daily activities, such as measurement of body temperature as an indicator of health, also rely on Fahrenheit's temperature scale and thermometer.

Fahrenheit's temperature scale remained in general use in most English-speaking countries until the 1970's. By that time, the centigrade (Celsius) scale, with 0 degree for the freezing point of water and 100° for its boiling point, had taken its place in most other countries and accepted worldwide by scientists.

—*Bruce E. Johansen*

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See also: Galileo; Gottfried Wilhelm Leibniz; Santorio Santorio; John Tyndall.

MICHAEL FARADAY

British physicist and chemist

Faraday's discoveries and inventions in chemistry, electrochemistry, and electromagnetism form the basis of modern science. He discovered the principles of electromagnetic rotation, electromagnetic and magnetoelectric induction, diamagnetism, and electrolysis.

Born: September 22, 1791; Newington (now in London), Surrey, England
Died: August 25, 1867; Hampton Court, Surrey, England
Primary fields: Chemistry; physics
Primary invention: Alternating-current (AC) generator

EARLY LIFE

Michael Faraday (FEH-ruh-day) was born to James and Margaret Faraday, a poor working-class family in Newington, London, in 1791. He was five when the family moved to Jacob's Well Mews, near Manchester Square. When he was nineteen, his father, a blacksmith, died from poor health, leaving his mother to support the family. The Faradays were Sandemanians, a Christian sect that believed in the literal truth of the Bible, pledging to live in imitation of Christ. Faraday maintained a separation between his religion and his science, both of utmost importance to him.

When Faraday was thirteen years old, he started work as an apprentice for George Riebau, a bookseller and bookbinder. Before this, Faraday's education had consisted of basic rudiments of reading, writing, and arithmetic at a common day school. A keen reader, he was influenced by Isaac Watts's book *On the Improvement of the Mind* and followed its suggestions for self-improvement.

Faraday's interest in science was first aroused by a chance reading of an article on electricity by the chemist James Tytler. Faraday was also fascinated by Jane Marcet's book *Conversations on Chemistry*, which was influenced by Sir Humphry Davy's lectures that she had attended at the Royal Institution. Soon enough, Faraday became a keen reader of Davy's books and an amateur experimenter of electricity. Thanks to the shilling fee paid by his brother Robert, Faraday joined a group of like-minded young men called the City Philosophical Society, attending lectures on scientific subjects and exchanging ideas with the group.

In 1812, Riebau showed some of Faraday's notes to one of his customers, William Dance, who was a member of the Royal Society. Dance was so impressed that he bought Faraday tickets for a series of lectures at the Royal Institution. Faraday had finished his seven-year apprenticeship with Riebau and was now a qualified bookbinder.

LIFE'S WORK

The lectures Faraday attended at the Royal Institution were given by the renowned chemist Sir Humphry Davy. Faraday took notes during the lectures and later wrote to Davy and sent him a well-bound copy of his notes. Davy was impressed but advised him not to leave his bookbinding job because it was almost impossible to earn a living as a scientist. Since finishing his apprenticeship with Riebau, Faraday had taken another bookbinding job at a bookshop owned by Henry de la Roche. Faraday was unhappy with his work, but some events occurred that changed his life.

Davy was temporarily blinded from an explosion during a chemical experiment and needed a secretary. He asked Faraday to help him until his eyes recovered. Then, Davy's assistant, William Payne, was dismissed for misconduct, and Faraday was hired in his place in March, 1813, although he earned less than as a qualified bookbinder. He was allowed to live in the Royal Institution.

In October, 1813, Davy and his wife arranged to go to Europe on an extended honeymoon and to meet with famous scientists there. They took Faraday with them to Paris, Switzerland, and Italy. Faraday enjoyed his exposure to Europe's famous scientists, including Alessandro Volta and André-Marie Ampère, who both worked on electricity, but he had problems with Davy's wife, who treated him like a servant.

On their return to London after eighteen months, Faraday began his own experimental work while engaged as Davy's assistant. Encouraged by Davy, Faraday began lecturing on chemistry topics at the City Philosophical Society and published his first scientific paper in 1816, "Analysis of Native Caustic Lime of Tuscany."

Faraday had earned a reputation as an analytical chemist, and in 1820 he produced the first known compounds of carbon and chlorine. This year, several scientists in Paris, including François Arago and André-Marie Ampère, made significant advances in establishing a relation between electricity and magnetism. Hans Christian Ørsted demonstrated the magnetic effect of an electric current. Davy became interested, and this gave Faraday the opportunity to work on the subject. In October of the following year, Faraday published "On Some New Electro-Magnetical Motions, and on the Theory of Magnetism" in the *Quarterly Journal of Science*.

In 1821, Faraday married Sarah Barnard, also a member of the Sandemanian church. The Faradays lived in rooms over the Royal Institution called the Upper Chambers, from which a back staircase led directly to the laboratory in the basement. It was there that Faraday made his first electrical discovery, on electromagnetic rotation—the principle behind the electric motor. He gave regular courses and routine lectures and was involved in the organization of the various activities of the Royal Institution.

From 1821, for the next twenty years, Faraday made one scientific discovery after another, both in chemistry and electricity. In 1823, he worked on the liquification of gases. His first major contribution to chemistry, the discovery of benzene, followed two years later. He discovered the laws of electrolysis in 1832 and the laws of electrochemistry the following year. He devised new scientific words like "electrolysis," "cathode" and "anode." He was thirty years old when he discovered the principle of electromagnetic rotation; forty years old when he discovered the law of electromagnetic induction, which allowed him to produce the first electrical generator and transformer; and fifty-four years old when he discovered the magneto-optical effect and diamagnetism.

In 1824, Faraday was elected a fellow of the Royal Society. Davy opposed his election but was overruled. Davy nominated him for the position of secretary of the newly founded club the Athenaeum. As soon as the club had become well established, Faraday resigned the office of secretary while remaining an ordinary member. In the mid-1820's, Faraday, an excellent and eloquent lecturer, established the Royal Institution Christmas Lectures, a celebrated series for young people. From 1829 to 1852, he was professor of chemistry at the Royal Military Academy at Woolwich. He was in demand to give practical advice, commercial analysis, expert testimony, and public service. For example, in 1836 he became chief scientific adviser to Trinity House, the foundation responsible for the maintenance of coastal installations such as lighthouses and buoys.

Michael Faraday. (NARA)

In 1832, Faraday received honors for his major contributions to science and an honorary degree from Oxford University. In February, 1833, he became Fullerian Professor of Chemistry at the Royal Institution. Further honors, such as the Royal Medal and the Copley Medal from the Royal Society, followed. In 1836, he was made a member of the Senate of the University of London.

Extremely overworked, Faraday had a nervous breakdown in 1839. As soon as he regained his health in 1845,

THE AC GENERATOR

Michael Faraday's famous experiments in 1831 led to his discovery of the law of electromagnetic induction, which paved the way for his invention of the generator. By reversing the 1820 discovery of Hans Christian Ørsted, Faraday reasoned that if a current running through a coiled wire could produce a magnetic field, then a magnetic field could induce or generate a current of electricity in a coil of wire.

A generator is a machine that induces electricity. Originally, the term "dynamo" was applied to both alternating-current (AC) and direct-current (DC) generators, but today it applies to DC only, while the term "alternator" is applied to AC generators. Generators can either have direct current or alternating current. AC generators are primarily used today. The DC generator induces a steady flow of current in the same direction. Batteries use DC: They are filled with two different pieces of metals with different electrical properties, and electricity goes round and round in the same direction. In the AC generator, the electric current flows back and forth in alternating waves when the magnet is rotated rapidly at a regular rate.

An AC generator can be described in terms of its components: In a U-shaped magnet, a coil of wire is suspended in the middle of the magnet. The magnet itself is split into two parts, or poles (north and south), of the magnet. The two poles create a force of attraction between them. The coil of wire, situated between the force field generated by the two magnets, is attached to a shaft called a prime mover. The prime mover transfers motion energy to the generator. The coil of wire spins in the force field, generating a steady flow of electrons in the wire. This flow of electrons is called electricity. In essence, the coil of wire acts as a conductor used to induce voltage. Either the conductor or the magnetic field must be moving for induction to occur.

Today, electricity is produced by generators that still operate under Faraday's basic conditions, including in large power stations. Portable generators are also used in homes, offices, hospitals, stores, and factories during times of electricity blackout or in times of emergency.

he resumed work on magnetism as a follow-up of William Thomson's mathematical treatment of his ideas on "lines of force." This led to Faraday's discovery of diamagnetism.

By the mid-1850's, Faraday was spent but continued to deliver his Christmas lectures. He gave lectures on various forces of matter and on the popular chemical history of the candle. In 1864, he declined the presidency of the Royal Society, and he resigned all remaining duties the following year. Queen Victoria gave him a Grace and Favour House at Hampton Court, a tribute to his distinction. As his mental faculties declined, Faraday gracefully retreated from the scientific world he dearly loved.

IMPACT

Faraday is considered one of the greatest experimental scientists in history, best remembered for his work in electricity. His discoveries and inventions have become viable for use in technology.

Electricity generation in large powered stations and portable generators use Faraday's principle of electromagnetic induction. His electromagnetic rotary device formed the foundation of the electric motor. Televisions, computers, radios, washing machines, vacuum cleaners, CD players, food mixers, and myriad domestic appliances rely on transformers, the first of which was invented by Faraday.

In chemistry, Faraday is remembered for his discovery of benzene, an aromatic chemical compound that has been used in various types of medicines, perfumes, and dyes. He discovered toluene and the xylenes, starting materials for a wide range of consumer products. Transport relies on components made from aromatic-based products. For example, a car's body, bumpers, lighting, dashboard, seats, upholstery, and underbonnet components are all derived from aromatics. Some derivatives of benzene are key ingredients of aspirin and penicillin. Plastic, acrylic, and nylon are reliant on aromatics.

Faraday's groundwork for the magnetic field concept was extended to form the basis of the first full mathematical description of the nature and interaction of electricity and magnetism, known as the electromagnetic theory. After his death, work was taken up by James Clerk Maxwell, whose theory of the electromagnetic field was built on the foundations laid by Faraday.

Faraday's final series of lectures were published and became classics. The Royal Institution Christmas Lectures, established by Faraday in the mid-1820's, continue to this day and reach a wide audience through television.

—*Tel Asiado*

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See also: Charles Babbage; William Fothergill Cooke; Sir William Crookes; Sir Humphry Davy; Sir James Dewar; Albert Einstein; William Francis Giauque; Sir William Robert Grove; Joseph Henry; Carl von Linde; Ira Remsen; Werner Siemens; William Sturgeon; John Tyndall; Alessandro Volta.

PHILO T. FARNSWORTH

American electrical engineer

Farnsworth's all-electronic television system was one of the great technological inventions of modern times. His patents encompassed not only advances in television scanning, imaging, focusing, synchronizing, controls, contrast, and power but also the first simple electron microscope and first infant incubator.

Born: August 19, 1906; Indian Springs, near Beaver, Utah
Died: March 11, 1971; Salt Lake City, Utah
Also known as: Philo Taylor Farnsworth (full name)
Primary fields: Electronics and electrical engineering; physics
Primary invention: All-electric television

EARLY LIFE

Philo Taylor Farnsworth (FI-loh TAY-lur FAHRNZ-wurth) was born to Lewis Edwin and Serena Bastian Farnsworth in the small farming community of Indian Springs, Utah, in 1906. As a young boy, he learned the skills of survival and the importance of hard work from his parents, but he was only an average student in school and showed no signs of genius. When he was twelve, his family moved to a ranch in Rigby, Idaho. There, he found science magazines in the attic of his new home and became enthralled with reading about electricity, magnetism, and the transmission of electromagnetic waves. He was fascinated by inventions, particularly the light bulb and the telephone, and how they worked. While still twelve years old, he built an electric motor and assembled the first electric washing machine that his family ever owned. At thirteen, he won a prize from *Science and Invention* magazine for inventing a theft-proof automobile ignition switch.

At Rigby High School, Farnsworth distinguished himself in physics and chemistry. He sketched prototypes of electron tubes and other electronic devices. While tilling a potato field back and forth with a horse-drawn harrow at the age of fourteen, he realized that an electron beam might be used to scan images in a similar way, line by line. He frequently thought about the fruition of that idea. He imagined a vacuum tube that could reproduce images electronically by shooting a beam of electrons, line by line, against a light-sensitive screen. It was a dream that he never abandoned. In 1922, he drew a diagram on the chalkboard for Justin Tolman, his chemistry teacher, that illustrated the concept of sending images using electromagnetic waves—the fundamental concept of electronic television. In 1923, Farnsworth left

Philo T. Farnsworth with television equipment he invented. He sold his television patents to RCA Victor for $1 million in 1939. (Time & Life Pictures/ Getty Images)

Rigby to attend Brigham Young University in Utah. After he had been there for two years, his father died, and he returned to Idaho to help support his mother.

LIFE'S WORK

During the early 1920's, many older engineers with significant financial backing were working to develop television. They included Charles Francis Jenkins, Boris Rosing, Kalman Tihanyi, Vladimir Zworykin, and John Logie Baird. The first electromechanical transmission of pictures had been demonstrated by German scientist Paul Nipkow in 1884, followed by the electromechanical transmission of the silhouette image of a toy windmill by Jenkins in the United States in 1925 and the production of the discernible image of a human face with an electromechanical television system developed by Baird in England in 1926. Farnsworth dedicated himself to inventing the first all-electronic television system. He understood the operation of mechanical systems that incorporated whirling disks to scan images, and mirrors to convert light into electrical signals. At best, these systems produced poorly resolved images. To address this problem, Rosing, Tihanyi, Zworykin, and others realized the importance of developing all-electronic systems for television transmission.

After Farnsworth obtained financial backing of $6,000 from George Everson in 1926 to pursue his ideas for electronic television, he and his beloved wife, Elma ("Pem"), moved to San Francisco. There, Farnsworth conducted the necessary research and development for his invention. By late 1926, he had developed models and blueprints for an all-electronic television system and applied for a patent. On September 7, 1927, he transmitted the first all-electronic television image, a straight line, using his newly developed camera vacuum tube, known as the image dissector.

On September 1, 1928, Farnsworth demonstrated his system for the media by transmitting the image of a dollar sign. After continuing to make improvements on his television system, he founded the Farnsworth Television and Radio Corporation in 1929. That year, his wife became the first human being to appear on television when Farnsworth transmitted her image across his laboratory in San Francisco.

In 1930, Zworykin, who was then working for the Radio Corporation of America (RCA), visited Farnsworth's laboratory and gathered detailed notes about Farnsworth's system. Farnsworth was under the impression that the visit was of a friendly, scholarly nature, to discuss the scientific and engineering aspects of television, not one that would lead to competition. In 1931, Farnsworth and his family moved to Philadelphia so he could establish a television department for the Philadelphia Storage Battery Company, which became better known as Philco. Meanwhile, Zworykin used the information that he had gathered about Farnsworth's television system to develop an improved camera tube, the iconoscope.

After Farnsworth rejected RCA president David Sarnoff's 1931 offer of $100,000 for his television patents, an ugly court battle ensued between RCA and Farnsworth. RCA contended that a 1923 patent held by Zworykin had priority over any of Farnsworth's patents. However, RCA failed to produce sufficient evidence that Zworykin had actually produced an operable electronic television transmitter in 1923. Even more damning to RCA's case was the production by Farnsworth's high school chemistry teacher of the sketch of an all-electronic system Farnsworth had drawn for him in 1922. In 1935, the U.S. Patent Office awarded priority of the invention of an all-electronic television system to Farnsworth. After transmitting regular entertainment programs experimentally, Farnsworth sold his television patents to RCA Victor for $1 million in 1939.

After World War II, Farnsworth devoted his efforts to perfecting the many electronic devices that he had invented. During the 1950's, he developed submarine detection devices and an infrared telescope. During the 1960's, he worked on special applications of television, missile design, and peaceful uses of nuclear energy, particularly nuclear fusion. By 1965, he had developed and patented an array of tubes, called fusors, that could generate thirty-second fusion reactions.

In 1968, Brigham Young University awarded Farnsworth an honorary doctor of science degree for his great scientific achievements. After Farnsworth died three years later, his wife worked hard to ensure that he was recognized for his inventions and that he received his rightful place in history. In 1983, the U.S. Postal Service issued a stamp bearing his portrait. The Pennsylvania Historical and Museum Commission honored Farnsworth with a marker in Wyndmoor, Pennsylvania, where Farnsworth had established a television shop in 1933. The marker recognizes Farnsworth as the "inventor of electronic television." He was inducted into the National Inventors Hall of Fame in 1984. Six years later, a bronze statue of him was placed in the Statuary Hall in Washington, D.C., with a simple inscription: "Philo Taylor Farnsworth: Inventor of Television." The full name of the Emmy Engineering Award that is presented annually to an individual, company, or organization that develops significant improvements or innovations in the transmission, recording, or reception of television is the Philo T. Farnsworth Corporate Achievement Engineering Award.

THE ALL-ELECTRIC TELEVISION

Philo T. Farnsworth was the first person to solve the problem of coordinating electronically scanned television cameras and electronically scanned television receivers that produced clear moving images. As his ideas evolved, a basic television camera came to consist of a lens, a system of mirrors, camera tubes, and complex electronic circuits. By scanning objects and dividing images into hundreds of thousands of parts (pixels), television cameras transform light from objects or scenes into streams of electrical impulses. Each pixel is an electrical signal that measures the amount of light recorded at a particular location. At the same time that television video signals are generated, microphones receive and change sounds into audio signals. Encoder circuits convert the video and audio signals into electromagnetic waves that are amplified and transmitted from broadcasting antennae. In the past, these waves were generally transmitted through the atmosphere. To send signals greater distances, microwave relay towers, satellites, coaxial cables, and fiber-optic cables were later employed.

Receiving television antennae pick up transmitted electromagnetic waves. Electronic circuits unscramble the electromagnetic signals and convert them back into electrical and audio impulses that mimic those originally sent out by the television camera and microphone systems. The video impulses travel to the picture tubes, which originally comprised electrical circuits and phosphor-covered screens divided into grids of pixels. Incoming video signals controlled electron guns that swept back and forth across the screens, hitting each phosphor pixel in turn, row by row, until the entire screens were covered. Each pixel received a burst of energy that told it how much to glow, thus converting the electrical signals into patterns of light that duplicated the televised scene. Until the late twentieth century, when new technologies appeared, the video camera tube developed through the combined work of Farnsworth and Zworykin was used in all television cameras.

Farnsworth's invention of an all-electronic television system changed the world dramatically. By the early 1980's, a vast majority of Americans regarded television as their favorite leisure-time activity. As the public increasingly turned to television to learn about what was happening in the world, many newspapers folded. Television became an effective medium for advertising and selling myriad products. The dynamics of politics was forever changed as television opened the door for direct communication between politicians and the public. Televised professional football grew in popularity to rival baseball as the national sport.

IMPACT

Farnsworth was an independent inventor, an idea person who had the ability to initiate practical concepts and convince investors that his ideas could be implemented. His success came from being a workaholic who thrived on spending time thinking and tinkering in his laboratory. He had a vision of what electronics could do to improve the world and was often so immersed in his inventive work that he would forget to eat. In many ways, his inventive work marked an end to the era of independent inventors. His contributions included the development of radar systems, vacuum tubes, electron microscopes, incubators, nuclear energy, and all-electronic television.

For many decades prior to Farnsworth's success with television, inventors had sought to devise telecommunication devices that might carry pictures and sounds from distant locations into the homes of the general public. Realizing that inventions were creations of people who dedicated their lives to such advancements and that being an inventor was a noble pursuit, Farnsworth devoted his life to inventions that would benefit the lives of others. Through dedication, persistence, hard work, and courage to stand up against a giant corporation (RCA), Farnsworth succeeded in developing an all-electronic television system, one of the greatest inventions of the twentieth century.

By the early 1980's, virtually every American household had at least one television set, each of which used at least six of Farnsworth's patented inventions. Without those six inventions, television would have remained a radio. By then, television was a major resource for entertainment, broadcasting the news, advertising, political campaigns, and education. Farnsworth had invented a medium that changed the world. As the impact and influence of television grew throughout the world, Farnsworth became one of its earliest and most perceptive critics, sometimes wishing that he had not been responsible for its invention, while realizing the great good that it might accomplish.

—*Alvin K. Benson*

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See also: Ernst Alexanderson; Lee De Forest; Regnald Aubrey Fessenden; Vladimir Zworykin.

JAMES FERGASON

American physicist

Fergason was the first person to invent a practical liquid crystal display (LCD) screen, which provided good visual contrast, used minimal power, and had a long lifetime. His inventive genius and insights into the physics and technology of LCDs have revolutionized industries that manufacture computer displays, consumer electronics, and many medical and industrial devices.

Born: January 12, 1934; Wakenda, Missouri
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Practical liquid crystal displays (LCDs); twisted nematic field effect

EARLY LIFE

James Fergason (FUR-gah-suhn) was born and reared in rural Missouri. The youngest of four children, Fergason grew up in a family that promoted education and instilled in him a desire to be a scientist. His father was a farmer, a postmaster, and a teacher. His grandfather graduated from college at the age of fifteen. Young Fergason loved reading science books and experimenting with rockets and chemicals. Even at a young age, he liked to invent things. After graduating from a small high school, Fergason attended the University of Missouri and earned a bachelor's degree in physics in 1956. After serving a six-month stint in the U.S. Army, he went to work doing research for Westinghouse Research Laboratories in Pittsburgh, Pennsylvania, in 1957, where he worked for the next ten years of his life.

Needing a way to measure the accuracy of temperature-measuring devices, Fergason became intrigued with liquid crystals because of their sensitivity to temperature fluctuations and their ability to reflect colors. At Westinghouse, he formed and led the first industrial research group to research liquid crystals and pursued possible commercial applications of these unique materials. In 1963, he received his first patent for the application of cholesteric liquid crystals in temperature-sensing applications. It was the first practical application of liquid crystals to be patented. His technique is still used for making devices that range from forehead thermometers to mood rings. In 1965, Fergason received the IR 100 Award from *Industrial Research Magazine* for inventing one of the one hundred most significant inventions of the year.

LIFE'S WORK

In 1966, Fergason accepted the position of associate director of the Liquid Crystal Institute at Kent State University. His primary focus was the application of liquid crystals to be used in thermal mapping as a screening tool for breast cancer. During his research, he observed that liquid crystals are naturally twisted together. After some experimentation, he discovered that they could be untwisted by applying an electrical voltage. This phenomenon was termed by Fergason as the "twisted nematic field effect" of liquid crystals. He found that varying the degree of twisting by changing the applied voltage controlled the amount of light that traveled through liquid crystals. The process could be accomplished with very little energy, allowing the liquid crystal displays (LCDs) to maintain sharp visual contrast. Previous attempts to produce LCDs had required high power levels that quickly degraded the crystals and image.

After publishing a paper in 1970 that outlined several ways to manufacture nematic liquid crystal displays, Fergason left Kent State and formed his own company, the International Liquid Crystal Company (ILIXCO), in Menlo Park, California. He continued his research on liquid crystals and proceeded to commercialize LCDs. Numerous companies involved in manufacturing devices that required low-voltage applications, particularly photocopiers, watches, calculators, and medical devices, became interested in seeking Fergason for his inventive genius and technological expertise. At the time, products that used digital displays lost their battery life quickly, making them undesirable to most consumers.

In 1971, Fergason demonstrated the application of his patented twisted nematic liquid crystal cell (TN-LCD). Bulova Watch Company was the first to purchase his TN watch display cell. By 1977, consumers preferred LCDs over light-emitting diodes (LEDs) in digital watches. In the meantime, Fergason continued to invent myriad LCD applications, including surface-mode LCDs for use in welding helmets and polymer-dispersed liquid crystals (PDLCs) for use in privacy windows. He formed other companies to develop his inventions, including the American Liquid Crystal Company and Optical Shields, Ltd. During the 1980's and 1990's, he led self-funded research and technology programs that focused on the challenges associated with liquid crystal applications. In 1986, he was presented the Francis Rice Darne Memorial Award for outstanding technical achievements and contributions to LCDs. In 1989, Fergason was recognized with a Distinguished Inventor Award by the Intellectual Property Owners Association for his invention of liquid crystal nonlinear eye protection with subnanosecond response. The following year, he received the Quiet Hero Award from Application Design.

In 2001, Fergason founded Fergason Patent Properties (FPP) to license his inventions on a nonexclusive basis for expanding new markets for electronic displays. Under Fergason's direction, the company continues to develop new LCD-based technologies that include System Synchronized Brightness Control (SSBC), which improves the contrast and dynamic range of LCD televisions and computer monitors; enhanced stereo three-dimensional desktop monitors, which improve brightness, sharpness, and image definition at levels never previously achieved; and head-mounted projectors, which enable the use of in-service vehicles and systems to be used in simulation and training missions. Fergason also continues his state-of-the-art research on miniature and passive LCDs and liquid crystal safety devices. During his career as an inventor, he has successfully defended his patents in court twice and diplomatically dealt with numerous claims that some of his ideas and inventions were simple and obvious. He continues to look at every day as an adventure for discovering or inventing something new and useful.

LIQUID CRYSTAL DISPLAYS

Through research and inventive genius, James Fergason found numerous practical applications for liquid crystals, which are compounds that can flow and yet maintain their characteristic molecular orientations. Small temperature changes can change their color, making them particularly useful in mapping the location of warm blood vessels and tumors in the body, as well as fractures and flaws in metal parts used in industry. Small inputs of electrical or mechanical energy can disrupt the weak chemical bonds in liquid crystals and make the substance twist, rotate, or flow, making them particularly appealing for displaying images.

Fergason's most important invention using liquid crystals are liquid crystal displays (LCDs), used in pocket calculators, wristwatches, video games, computers, and televisions. LCDs contain a layer of numerous twisted nematic (TN) liquid crystal cells placed between two layers of polarized glass. Electrical contacts are made to the liquid crystal by embossing the layers of glass with a pattern of segmented electrode bars. When electrical voltage is applied across any segment in the display, the liquid crystal aligns with the applied electric field. Changing the applied voltage to the crystal in a precise pattern and at precise times can make the pattern tick off the seconds on a digital wristwatch, display letters on a computer screen, or form an image on a television screen. LCDs consume little energy and have a long lifetime.

Television LCD flat panels can be as thin as two inches thick, with larger ones no more than three inches thick. Light from powerful bulbs in the back of the panel move through a diffuser plate that distributes the light evenly across a screen. The light then passes through a layer of thin film transistors (TFTs) and color filters that control the amount of electricity passed into each liquid crystal cell. The result is hundreds of thousands of LCD pixels, each generating red, green, or blue color to produce the final image on a television screen or computer monitor. By using pixels to generate color, the scan lines produced by televisions that use cathode-ray tubes (CRTs) to scan the picture tube from top to bottom with an electron beam are eliminated, resulting in a smooth, evenly lit, saturated image across the entire display. LCD screens can be viewed under any lighting conditions, including very bright, sunlit rooms.

Although the liquid crystal display (LCD) screen was first made by George Heilmeier in 1968, Fergason has remained the consummate inventor of useful LCD devices for decades. His LCD inventions range from watches to television screens to eye protectors and surgical imaging devices.

IMPACT

Fergason is one of the leading American independent inventors and is recognized as the pioneer researcher of liquid crystals. His motto has always been to work hard and persist until success is achieved. If a mistake is made, Fergason believes in admitting it, correcting it as much as possible, and moving on to his next idea. His insights and inventions have been critical in moving liquid crystal research forward. His discovery of the twisted nematic field effect in liquid crystals and his numerous inventions derived therefrom have been instrumental in the development of the flat-panel LCD industry. His inventions and applications of LCDs include PDLCs for use in privacy windows that can change from clear to opaque by flipping a switch; surface-mode LCDs for use in three-dimensional video viewing systems and welding helmets; head-mounted displays for use in surgical imaging and aircraft flight training; and devices to protect eyes from the harmful effects of invisible infrared radiation and laser weapons. Through the pioneering efforts of Fergason, LCD technology has evolved into a multibillion-dollar industry that provides hundreds of millions of products to consumers.

In addition to his profound influence on the electronics industry, Fergason is a strong advocate of the interests of independent inventors. His famous 1970 paper that defined the making of nematic LCDs served as a launching pad for the evolvement of LCD technology and has been cited by hundreds of inventors. In 2000, he was appointed by the U.S. Secretary of Commerce as a member of the first Patent Public Advisory Committee. He has provided sound advice and counsel on policy and operational issues for the U.S. Patent and Trademark Office and developed a program that has improved patent quality.

From a corporate researcher, to a university lab director and researcher, to an independent inventor, Fergason has sustained a career of invention and innovation that has led to several key breakthroughs. Credited with over 150 U.S. patents and over 500 foreign patents in over forty countries, Fergason was inducted into the National Inventors Hall of Fame in Akron, Ohio, in 1998, the same year that he was awarded the Ron Brown Technology Award by the U.S. Department of Commerce. In 2001, he was presented with an honorary doctorate in science by the University of Missouri. In 2006, he was awarded the prestigious Lemelson-MIT Prize of $500,000 for his achievements in the field of liquid crystals. It is the largest cash prize given in the United States for inventions. In May, 2007, he was the recipient of the David Richardson Medal from the Optical Society of America for his contributions to optics and photonics.

—Alvin K. Benson

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Fisch, Michael R. *Liquid Crystals, Laptops, and Life*. Hackensack, N.J.: World Scientific, 2004. Presents the basic principles of liquid crystals and contains a systematic, practical treatment of the optics of LCD displays. The impact of the work done by Fergason and others with LCD applications in everyday life is recognized and highlighted.

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Wu, Shin-Tson, and Deng-Ke Yang. *Fundamentals of Liquid Crystal Devices*. Hoboken, N.J.: Wiley, 2006. This interdisciplinary book is an introductory guide to the fundamental principles of liquid crystals and their applications in display and photonic devices. In explaining the basic physics governing the optical and electro-optical phenomena associated with LCDs, some of Fergason's contributions are noted and discussed.

See also: Karl Ferdinand Braun; Stanford Ovshinsky.

ENRICO FERMI

Italian American physicist

Fermi helped develop Fermi-Dirac statistics, which elucidate the group behavior of elementary particles. He also developed the theory of beta decay and discovered neutron-induced artificial radioactivity. Finally, he succeeded in producing the first sustained nuclear chain reaction, which led to the discovery of nuclear energy and the development of the atomic bomb.

Born: September 29, 1901; Rome, Italy
Died: November 28, 1954; Chicago, Illinois
Primary field: Physics
Primary inventions: Controlled nuclear chain reaction; Fermi-Dirac statistics; theory of beta decay

EARLY LIFE

Enrico Fermi (ehn-REE-koh FUR-mee) was the third child of Alberto Fermi and Ida de Gattis. Enrico was very close to his elder (and favorite) brother, Giulio, and they shared an interest in physics and mathematics. Both were very intelligent and enjoyed building mechanical and electrical toys. Enrico's mother inspired her children by her own example of love, hard work, and discipline. When Fermi was about fourteen, Giulio died unexpectedly during a simple surgery. Fermi was devastated and for diversion devoted himself to deeper and more challenging studies in physics and mathematics. Fortunately, he soon found a new friend in schoolmate Enrico Persico, who had similar interests. They enjoyed working together on many scientific projects, such as building gyroscopes and measuring the Earth's magnetic field.

Fermi was even more fortunate in finding a mentor in his father's friend and colleague Adolfo Amidei, a university-trained engineer. Amidei noticed Fermi's dedication to physics and mathematics and started lending him books on those subjects. One of the first books Fermi borrowed was on projection geometry, a difficult subject. When Fermi returned it in about two months, he had mastered all the chapters and had solved all the problems in the book—about two hundred of them. Amidei was very impressed, since he had found some of these problems too difficult to solve. Over the next four years, Fermi was introduced to books on other branches of mathematics. Fermi excelled at solving problems and was blessed with a prodigious memory.

In July, 1918, Fermi received his diploma from the *liceo* (secondary school) and, on the advice of Amidei, joined the Scuola Normale Superiore at Pisa. This elite college, attached to the University of Pisa, admitted only forty of Italy's top students, who were given free board and lodging. Fermi performed exceedingly well in the highly competitive entrance exam. He completed his university education after only four years of research and studies, receiving his Ph.D. in physics from the University of Pisa and his undergraduate diploma from the Scuola Normale Superiore in July, 1922. He became an expert theoretical physicist and a talented experimentalist. This rare combination provided a solid foundation for all his subsequent inventions.

LIFE'S WORK

After postdoctoral work at the University of Göttingen, in Germany (1922-1923), and the University of Leiden, in the Netherlands (fall, 1924), Fermi took an interim position at the University of Florence in December, 1924. The following year, he wrote an important paper in statistical mechanics, which led to his first important discovery, known as Fermi-Dirac statistics. (Paul Dirac published his independent discovery in 1926.) At the atomic level, the behavior of particles such as electrons, protons, and neutrons is governed by quantum mechanics. Fermi's statistical theory helped to explain the group behavior of the particles, later named fermions. The statistical theory also helped to explain the atomic structure of elements, the conduction of electrons in metals and semiconductors, and even the structure of neutron stars.

In 1926, Fermi became a tenured professor at the University of Rome and in the same year developed his second important theory: a theory that explains the emission of beta particles (electrons) from radioactive elements. Fermi used the newly postulated particle, the neutrino, for energy conservation and introduced the concept of the weak nuclear force to explain the beta decay. This force became known as one of the four fundamental forces in the universe. (The others are gravity, electromagnetic force, and the strong nuclear force.) The characteristic constant for the weak force is now known as Fermi's constant.

After getting a secure job at the University of Rome, Fermi married Laura Capon on July 19, 1928, and they had two children. This was a very productive period in Fermi's life. His friend and former colleague Franco Rosetti had joined him in 1927. With Fermi's graduate students, Edoardo Amaldi and Emilio Segrè, they formed a research team. Their work led to Fermi's most important discovery, the artificial radioactivity induced by neutrons. Fermi realized that neutrons, being neutral in charge, make good projectiles to bombard a target atomic nucleus. Fermi embarked on a detailed and careful study of neutron-induced radioactivity in various elements and discovered a number of new forms of these elements (isotopes) that are artificially radioactive. Fermi and his team published ten papers in four years. This systematic work ultimately garnered a Nobel Prize in Physics for Fermi, in 1938. During these experiments, Fermi also discovered a surprising result. When he slowed down the neutrons by passing them through a hydrogenous matter, such as paraffin, radioactivity increased significantly. The slow neutrons seemed to interact with a nucleus much better than fast neutrons. This discovery proved to be of enormous significance for Fermi's subsequent work on sustained nuclear chain reaction and the creation of an atomic bomb.

Meanwhile, the political situation in Italy was becoming tense: As World War II approached, the Jewish community faced increasing restrictions. Fermi's wife was Jewish, and the couple decided to immigrate to the United States. After Fermi received the Nobel Prize in Sweden, he and Laura, along with their two children, embarked on their journey to a new world. They reached the United States on January 2, 1939, and Fermi started teaching at Columbia University in New York.

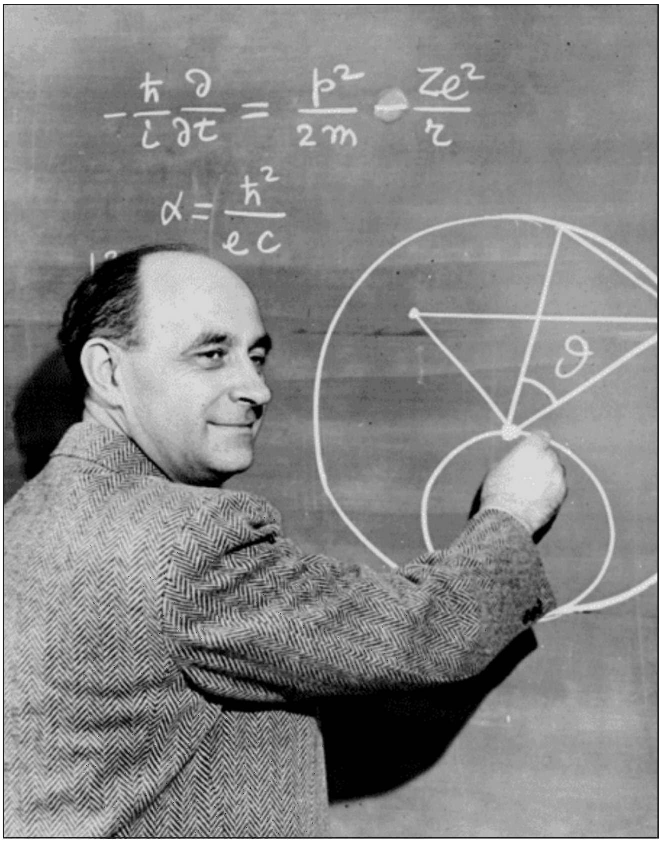
Fermi's major effort in the United States was to produce the first controlled chain reaction through nuclear fission. During his research at the University of Rome on artificial radioactivity induced by neutrons, Fermi had bombarded the element of the highest atomic number then known, uranium. His research team expected to produce transuranic elements (elements with greater atomic numbers) through artificial radioactivity. What really happened was that the heavy uranium nucleus split into two, a process called nuclear fission. Fermi, unfortunately, did not realize this during his experiments in 1935, and this very important process was discovered independently by another group in Germany three years later. The discovery of nuclear fission and chain reactions became enormously important in the context of World War II, started in Europe around that time.

Fermi started working on producing a controlled chain reaction in 1939 at Columbia University and then moved to the University of Chicago in 1942, where the first sustained nuclear chain reaction was produced on December 2 under his leadership. Around this time, the United States entered the war, and the development of an atomic bomb became a high priority. In 1944, Fermi moved to Los Alamos, New Mexico, to become an associate director in the Manhattan Project, which successfully produced the atomic bomb in 1945. The use of this bomb against Japan in August, 1945, brought the war to an end.

Soon after, Fermi returned to the University of Chicago to continue his teaching and research. After nine productive years, he died on November 28, 1954, from cancer. Only one month before his untimely death, Fermi received a special twenty-five-thousand-dollar award from the Atomic Energy Commission.

IMPACT

Fermi was one of the top physicists of the twentieth century. His studies on the statistical group behavior of fermions and his theory of beta decay have led to tremendous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Enrico Fermi. (NARA)

progress in atomic and nuclear physics. Every atom in this world contains fermions, which include electrons, protons, and neutrons. Hence, the Fermi-Dirac statistics have added to our understanding of the world at a deep, subatomic level. A clear understanding of atomic structure, in turn, has made possible the development of such advancements as semiconductors, lasers, and spectral studies.

Fermi's study of neutron-induced artificial radioactivity also led to the discovery of several new radioactive isotopes. These "radioisotopes" are now widely used in medicine, agriculture, industry, and research. Fermi's success in producing the first controlled nuclear chain reaction had the greatest impact on the lives of people, leading to alternative sources of energy, powerful nuclear weapons, and a variety of by-products.

Not only a brilliant physician, Fermi was also a respected teacher and colleague. After his death, an award inaugurated by the Atomic Energy Commission and given to Fermi was renamed the Fermi Prize with an increased value of $100,000. There is the great monument, the Fermi National Accelerator Laboratory (Fermilab), near Chicago. In 1955, the year after his death, the new radioactive element of atomic number 100 was named fermium in his honor.

—*Rajkumar Ambrose*

THE FIRST ATOMIC PILE

Scientists were aware that the atomic nucleus had the potential to produce enormous energy. This potential became a reality with the discovery of nuclear fission in 1938 and the construction of the first atomic pile by Enrico Fermi in 1942. The atomic pile designed by Fermi and his team was constructed in an abandoned squash court in the football field of the University of Chicago, and the work began in October, 1942. The builders had to machine two hundred tons of pure graphite and secure about six tons of uranium, which were to be arranged layer by layer in alternate lattices to create a roughly spherical structure. Fermi's calculations showed that the pile would reach critical size at the fifty-seventh layer, and it did. There was a lot of suspense before that.

Fermi and his colleagues assembled in the squash court at 8:30 A.M. on December 2, 1942. The pile included cadmium control rods, which would absorb neutrons and control the chain reaction. These included electrically operated rods, an emergency safety rod, and a manually controlled rod. At 9:45 A.M., Fermi ordered the electrically operated rods to be withdrawn. Neutron counters indicated the activity of the pile as the control rods were withdrawn. Shortly after 10:00 A.M., Fermi ordered the emergency rod to be pulled out and locked. The manually operated control rod had markings to show what length was inside the pile.

At 10:37 A.M., Fermi ordered the control rod to be pulled to the thirteen-foot marking. The neutron count increased and leveled off. Seven minutes later, Fermi ordered the rod to be pulled out by another foot. The counters stepped up their clicking, and the graph pen edged upward and soon leveled off. The pile was not self-sustaining yet. The control rod was pulled out farther at 11:00 A.M., 11:15 A.M., and 11:25 A.M., and each time the counts increased and leveled off. Each time, Fermi made the necessary calculations using his slide rule. At 11:35 A.M., Fermi's calculations indicated that the pile would go into operation soon after. Fermi then called for a lunch break.

The group reassembled at 2:00 P.M. to resume the operation. At 2:20 P.M., the manual control rod was pulled out to its pre-lunch position. It was pulled out six inches at 2:50 P.M. and by another foot at 3:20 P.M. The counters were running wildly, and five minutes later Fermi gave the final order to pull the control rod by another foot. The clicking of the counters became so rapid that it sounded like a roar. Now the neutron counts did not level off, and Fermi knew that the first atomic pile was in operation. After operating for twenty-eight minutes, the atomic pile was shut down by sending the cadmium rods back in. This historic event launched the nuclear age and laid the groundwork for the development of the atomic bomb.

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See also: Edward Goodrich Acheson; Luis W. Álvarez; Walther Bothe; M. Stanley Livingston; J. Robert Oppenheimer; Leo Szilard; Edward Teller.

REGINALD AUBREY FESSENDEN

Canadian electrical engineer

Fessenden developed the modern continuous carrier-wave radio, replacing radiotelegraphy with radiotelephony and making possible modern broadcast radio.

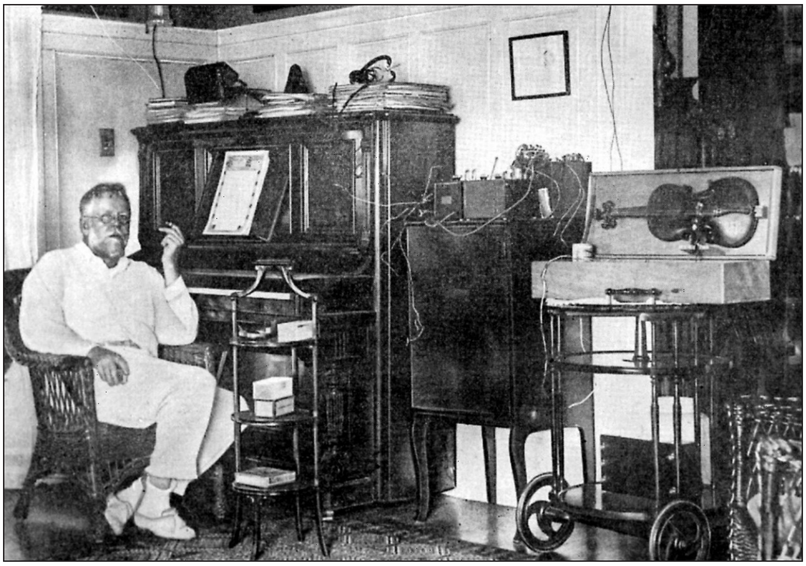
Born: October 6, 1866; Milton, Quebec, Canada
Died: July 22, 1932; Hamilton, Bermuda
Primary field: Communications
Primary inventions: Broadcast radio; radiotelephony

EARLY LIFE

Reginald Aubrey Fessenden (FEHS-uhn-duhn) was the son of an Anglican priest living in Canada. At an early age, Fessenden showed a prodigious intellect, one that alienated many of his peers. Like many very bright children, he simply did not realize that those around him did not think as quickly or as easily as he did and thus inadvertently showed up others in ways that created resentment. He also had incredibly fine close vision, such that an ophthalmologist who examined him compared his eyes to a microscope. However, his sharp nearsightedness came at the price of very poor distance vision, and as a result he found it necessary to wear glasses from childhood.

Because of his unusually quick mind, Fessenden progressed through school so rapidly that he was ready to begin college-level work at age fourteen. While studying for his bachelor's degree at Bishop's College, he worked as a high school mathematics teacher in Quebec. After some time in this position, he went to Bermuda to set up his own school. Although he met his wife there, he found it difficult to attract paying students. The paucity of intellectual life was even more frustrating, and to entertain himself he set to reading *Scientific American* back issues and became self-taught in a number of fields of science and engineering.

In 1886, Fessenden headed to New York, hoping to find employment as a writer. At the time, he was thinking primarily in terms of his formal education in the classics and humanities. However, while he was able to pick up the occasional freelance assignment, he was unable to obtain regular employment, and as a family man he no longer had the freedom to take risks with his finances. He



Reginald Aubrey Fessenden in an undated photo. On the evening of December 24, 1906, Fessenden broadcast a radio show from his station at Brant Rock, Massachusetts, reading, singing carols, and playing a violin solo of "O Holy Night." The broadcast was received by ships at sea along the Atlantic coast. It was the first time that radio was used as an entertainment medium. (AP/Wide World Photos)

RADIOTELEPHONY

When Guglielmo Marconi first invented radio, he thought of it primarily in terms of wireless telegraphy, turning the transmitter on and off to create controlled bursts of static. In fact, his technical adviser, John Ambrose Fleming, told him that this was the only way one could operate a radio. It would use Morse code to send messages for individuals, generally within the government or businesses, which would have to be decrypted at the receiving end and delivered by messenger boys to the intended recipients.

However, Reginald Aubrey Fessenden could see another paradigm. If one could make the transmitter run continuously to create a carrier wave, one could impose a complex signal upon it. Such a signal could even transmit such sounds as the human voice. His plan for doing so involved creating a special alternator that would turn at extremely high speeds, creating a high-frequency alternating current that would generate a continuous radio wave. However, every engineer that looked at his design told him it would fly apart the moment it was turned on.

Not to be discouraged, he created the next best thing. He took an Edison phonograph cylinder and milled it with ten thousand tiny horizontal grooves. When it was spun in his system, it would produce ten thousand sparks per second, a crude approximation of a carrier wave. On December 23, 1900, Fessenden climbed a tower on Cobb Island in the Potomac River and spoke into a microphone. The message was a simple one, a request for a weather report to be telegraphed back to him. The transmission was filled with static as a result of the crudity of the transmitter, but it was audible. Only in 1906 was Fessenden able to build the alternator he had envisioned, with the technical assistance of Ernst Alexanderson, a Swedish engineer who behaved more like an absentminded professor. On Christmas Eve of that year, Fessenden made a brief radio show that was heard up and down the Atlantic coast.

Unfortunately, Fessenden was unable to secure corporate backing. Commercial radio would remain wireless telegraphy for another decade, until a young executive at American Marconi by the name of David Sarnoff wrote a memo describing a "radio music box" with an infinite number of records, an appliance that ordinary people with minimal technical expertise would set up in their homes. By the time radio became a social force in the 1920's, the Alexanderson alternator was already giving way to enormous versions of the triode vacuum tube originally invented by Lee De Forest. In the later part of the twentieth century, semiconductor-based technology would replace vacuum tubes in transmitters.

finally sought a job with Thomas Alva Edison, hoping that his knowledge of mathematics and science would be of use to the famous inventor. Although his initial contact went awry, he was soon hired by Edison's chief machinist as a tester, responsible for locating and repairing breaks in New York City's buried electrical lines.

Fessenden was so successful as a tester that Edison took note of him, asking him to become a chemist. Fessenden excelled in this position and was made Edison's chief chemist. However, in 1890, Edison suffered a financial reverse, and Fessenden was laid off as a result.

LIFE'S WORK

By this time, Fessenden's technical skill had become sufficiently well known that he did not remain unemployed for long. George Westinghouse, who had made his fame and fortune with the air brake, had moved into electricity with Nikola Tesla's polyphase alternating-current system and was looking for engineers. Fessenden made a key improvement in the double-stopper light bulb, enabling Westinghouse to avoid infringing upon Edison's patents and to successfully electrify the 1893 World's Fair in Chicago.

Fessenden was dissatisfied with corporate life and decided to return to academia, this time as the head of Purdue University's new electrical engineering department. Still restless, he tried an engineering professorship at the University of Western Pennsylvania in Pittsburgh, but it did not satisfy him either, so he decided to try his hand as a civil servant. The U.S. Weather Bureau (a predecessor of the National Weather Service) was establishing a chain of radio stations on the East Coast to transmit weather information, and in 1900 Fessenden was able to work out a very agreeable contract with the agency by which he would retain the rights to all patents derived from work he did for the department.

What should have been a plum arrangement soon soured, as Fessenden became convinced that the chief of the Weather Bureau intended to steal his patents. They quarreled and he quit after firing off a hasty letter of protest to President Theodore Roosevelt. However, in that brief period of time, he achieved the key insight that was to make his fame—namely, that it was possible to create a radio transmitter that would produce a continuous carrier wave, upon which could be imposed complex signals, even the human voice.

His abrupt separation from the Weather Bureau made it very difficult to realize his vision. He and his wife had little personal savings, and venture capital was not easily found. An arrangement with two Philadelphians quickly foundered on Fessenden's inability to explain his concepts in terms understandable to someone not well versed in electrical theory. Hoping to generate some cash, he developed a new type of radio receiver that could easily be manufactured with off-the-shelf equipment, only to have it pirated by the U.S. Navy, which as a department of the federal government could not be sued, under the waiver of sovereign immunity.

When he did finally create his carrier wave-generating alternator, he failed to adequately publicize his first tests. As a result, his success in transmitting the human voice remained unknown to all but a few hobbyists and Navy radiomen. He had lost the opportunity to pique the public's interest with the possibility of a technology that did not require a skilled code operator to understand.

As a result, Fessenden found it difficult to gain support from investors, and although he continued to work assiduously to improve his system, eventually the funds ran dry. He then moved on to other applications of radio theory, including an iceberg detector, which should have been welcome after the spectacular RMS *Titanic* disaster of 1912 but was adopted only with painful slowness, again because Fessenden had no idea how to build publicity. His radio direction finder, which he called a "pelorus," would ultimately become the basis of the modern radio compass found in aircraft instrumentation, but very few people knew the tangled story of how it came to be.

During World War I, Fessenden developed an early form of long-wave radar sufficient to detect the Germans' airship raids. He also developed the concept of carpet bombing, but the notion of manufacturing thousands of bombers and sending them aloft in mass formation was too far outside the box for the British military commanders to grasp.

After the war, Fessenden became increasingly interested in the similarities among the Flood stories of the Greeks, Egyptians, Hebrews, and Babylonians. He became convinced that they had a historic and scientific basis, and he eventually developed a theory that a sudden melt of glacial ice at the end of the last Ice Age resulted in a sudden innundation of the eastern Mediterranean basin and the Levant. He was also one of the first to suggest that the legendary city of Atlantis might actually lie within the Black Sea rather than the modern Atlantic Ocean, although he did not go so far as to connect it with Troy (of Homeric fame).

By the 1930's, Fessenden had developed heart disease and had returned to Bermuda in the hopes of easing his worsening health. He died there in 1932. His tombstone reads, "I am yesterday and I know tomorrow"—written in Egyptian hieroglyphics.

IMPACT

Fessenden realized that radio waves could be made to carry the human voice. His invention eliminated the need for a trained code operator to transmit and receive wireless messages. With this technology, radio later became a medium for the masses. It remained only for David Sarnoff, himself a former code operator, to provide the business model, at Radio Corporation of America (RCA), that turned radio into an entertainment medium that would transform society.

—Leigh Husband Kimmel

FURTHER READING

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See also: Ernst Alexanderson; Edwin H. Armstrong; Karl Ferdinand Braun; Lee De Forest; Thomas Alva Edison; George Westinghouse.

JOHN FITCH

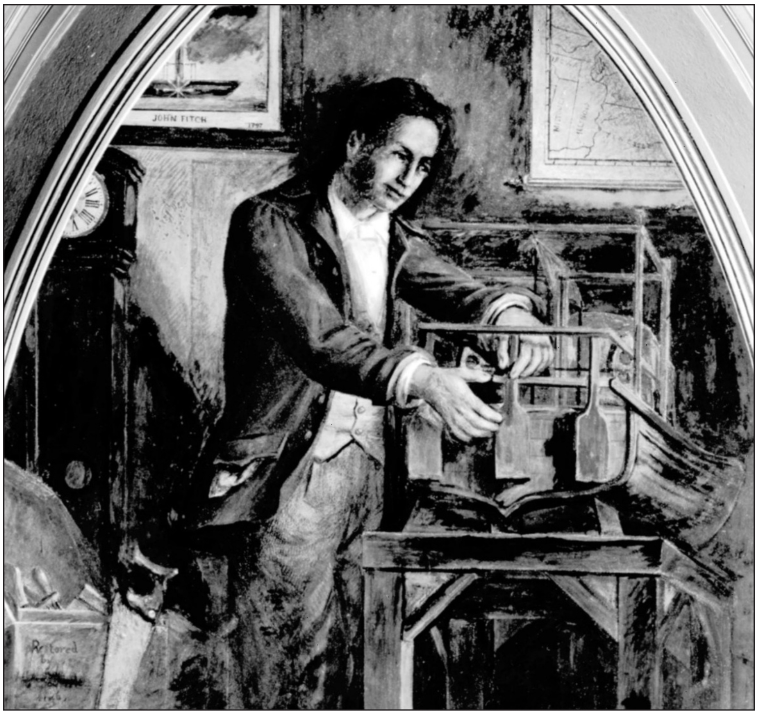
American industrialist

Widely considered the inventor of the steamboat, Fitch helped pioneer that type of vessel. In the summer of 1790, he ran a steamboat service along the Delaware River, demonstrating the practicality of such a craft.

Born: January 21, 1743; South Windsor, Connecticut
Died: July 2, 1798; Bardstown, Kentucky
Primary field: Naval engineering
Primary invention: Steamboat

EARLY LIFE

John Fitch was born in 1743 to Joseph Fitch and Sarah Shaler Fitch in the farming town of South Windsor, Connecticut. Fitch's mother died when he was only about four years old. His father remarried a few years later. Fitch attended school and showed great interest in learning. At the age of nine, however, his father pulled him from school so he could help around the farm. For the next few years, Fitch only had a month of schooling each year, in the winter. He read whenever he could, however, and taught himself mathematics. When he was thirteen years old, the local schoolmaster taught him surveying.



John Fitch. (Library of Congress)

Uninterested in farming, Fitch sought to find a trade when he reached the age of seventeen. Work as a seaman proved equally unappealing. He was then apprenticed to a clockmaker. His situation was unpleasant, however, and he was allowed to leave a few months before his time was complete. At the age of twenty-one, Fitch started his own business making brass objects and fixing clocks. He married an older woman, Lucy Roberts, in 1767, but their union was unhappy. Just a few years later, Fitch abandoned his wife and two children and left Connecticut.

Fitch ended up in Trenton, New Jersey, where he learned the trade of a silversmith and earned a good living making silver and brass buttons and repairing clocks. During the American Revolution, he made guns for the American forces. In 1776, when British forces moved into Trenton, Fitch fled to Pennsylvania. In 1781, he traveled to Kentucky—then part of Virginia—to survey land and buy parcels for himself and others. His purchase was in central Kentucky, near what became Bardstown. The next year, on a similar trip, Fitch was captured by Native Americans and handed over to their British allies.

When the Revolutionary War ended in 1783, Fitch was released. He spent much of the next two years surveying the Northwest Territory. Fitch applied to Congress for a government job as an official surveyor of that area. In the meantime, he produced a map of the region, but Congress never gave him the coveted job.

LIFE'S WORK

Fitch's disappointment was short-lived. In April, 1785, he had the idea that became his passion for the next decade and his claim to fame: He thought of designing a vessel that could be powered by steam. Initially, Fitch envisioned a steam-powered carriage but soon dismissed that as impractical, turning his mind to a steam-powered boat. What exactly inspired this idea is unclear. He is not known to have ever seen a steam engine, though there was one in New Jersey in the 1750's and 1760's that he might have seen during his travels. It is also possible that he had heard of James Rumsey's proposal to develop a boat equipped with paddles that could be powered without oars or sails. Whatever the impetus, Fitch lost little time in pursuing his idea. In the summer of 1785, he built a small model of a boat, which would move by means of a steam engine rotating a series of side-mounted paddles. In August, he took his plan to Congress, hoping for encouragement—and money. He received neither. He also presented his plan to the members of the American Philosophical Society and was again disappointed by the unenthusiastic response.

Fitch met with influential people in Maryland, Virginia, Pennsylvania, and Delaware in the hopes of winning an endorsement, which could lead to funding. Success finally came in March, 1786, when the New Jersey legislature gave Fitch the sole right to run a steamboat business on the state's waterways. Soon after, Fitch met a Philadelphia man named Henry Voight, who had considerable mechanical aptitude. The two became a team and set to work.

For the next several years, the pair worked on the idea, changing designs and components as trial runs introduced new problems. Fitch and his investors wanted to develop a method of water travel that would be sufficiently fast and inexpensive to compete with the stagecoaches that carried people overland. A stagecoach trip from Philadelphia to Trenton took about five hours. A boat traveling the Delaware River needed to go about eight miles per hour to at least match that speed. If it did, and they could convince enough passengers to take the novel conveyance, Fitch and Voight could make money. Fitch had a secondary goal as well: He believed that steam-powered river travel would be of great help to the United States as it expanded to the West.

FITCH'S STEAMBOAT

John Fitch's steamboat design called for placing a brick furnace in a wooden boat. The fire in the furnace heated water in a boiler, releasing steam. The steam entered a cylinder, forcing a piston to move. The piston's motion moved a shaft, which moved paddles that turned, propelling the boat. Fitch and Henry Voight had to make several adjustments to these original ideas to make their steamboat work.

Their first plan called for a cylinder only three inches in diameter, but that was not strong enough to move a twenty-ton boat. Fitch calculated that they needed a twelve-inch cylinder. When the engine was tested on land, the piston leaked. Placing the cylinder vertically fixed that problem. The men also built a larger boiler. When they tested their vessel on water in August of 1787, the boat moved, but not fast enough to make the steamboat an economical mode of travel. Fitch figured that he needed an eighteen-inch cylinder. Unable to get a working version from an iron foundry, Fitch found another solution: He would make the boat longer and narrower and cut the vessel's weight. These steps, he believed, would lessen the need for power and allow the smaller cylinder to work. Once again, the boat succeeded. Fitch and Voight not only steamed up the Delaware for about twenty miles from Philadelphia to Burlington, New Jersey, but also carried thirty passengers. Still, the speed they reached—about five miles per hour—could not compete with a stagecoach running on land.

Fitch persevered, raising enough money to build the eighteen-inch cylinder, but disaster struck. The first version failed to work; the second did not provide enough power. Worse, sparks that remained in the furnace after a test run started a fire that destroyed the boat. Fitch tried one more modification—moving the paddles from the sides of the boat to the stern. He never offered an explanation for this switch, but it proved helpful. On April 16, 1790, Fitch took his boat onto the Delaware River and steamed past every sail-powered and oar-driven vessel on the water. The boat had no mechanical problems. Fitch's dream was now a reality.

Fitch named his boat the *Perseverance*, an apt name, for he showed great tenacity despite repeated failures and obstacles, including the loss of faith among his backers, running out of money more than once, and a fire that destroyed the wooden hull of one trial boat. Nevertheless, on April 16, 1790, the two men successfully ran the *Perseverance* up the Delaware River. Fitch and Voight gleefully watched as they steamed past every vessel on the water—including one that had a mile-and-a-half head start.

The next step was to prove the new invention to be practical. Cabins were built on the boat, and advertisements were placed in local newspapers telling the public of the new steamboat service. That summer, Fitch's boat made dozens of trips up and down the river, logging as many as three thousand miles. While the engine sometimes broke down, it was always easily and quickly fixed. The steamboat clearly worked, but it was not commercially viable. The public was wary of riding in the new vessel, and it was neither fast enough nor cheap enough, compared to a stagecoach, to convince people to overcome their doubts. Riders were few, and Fitch's investors were disappointed.

The inventor suffered an even bigger blow that summer. Fitch hoped to guarantee his place as the inventor of the steamboat by applying to the U.S. government for a patent under a new patent law. On August 26, 1791, he did receive a patent for a steamboat—but so did Rumsey, who had by then independently developed the idea of using steam engine to power his boat. In fact, two other inventors received patents as well. Fitch was crushed. In the fall, Fitch's company persuaded an agent in France to obtain a patent for Fitch's steamboat. Two years later, Fitch traveled to France to build the boat and try to make his fortune. The country was in the midst of a particularly bloody period in its revolution, however, and Fitch's efforts did not advance. The following year, he returned to the United States.

Fitch's remaining few years were spent in bitterness and frustration. In 1797, he moved to Kentucky, settling in Bardstown, where he passed time building a model steamboat and a model of a steam-powered land vehicle. Now on display at the Ohio Historical Center, it is the first model of a railroad locomotive. On June 25, 1798, he wrote a will and had it witnessed. By most accounts, he then set his mind to suicide, overdosing on opium pills the following month.

IMPACT

Some experts credit James Rumsey as the inventor of the steamboat. However, Rumsey never carried his idea as far as Fitch did. Fitch's many trips up and down the Delaware in the summer of 1790 amply demonstrated that a steamboat was a viable means of transportation. Fitch was unfortunate, however, in his choice of location to launch his business, and perhaps unlucky in timing. Stagecoach travel between Philadelphia and Trenton was reasonably rapid and well established when Fitch launched his service. In addition, in 1790 people were not ready to ride on a steamboat. Seventeen years later, Robert Fulton enjoyed much more success with his steamboat that carried passengers between New York City and Albany along the Hudson River. That success came even though Fulton's *Clermont*, which traveled an average speed of five miles per hour, was actually slower than Fitch's boat. The explanation for this success is simple: Stagecoach travel was not as competitive with steamboat travel along the banks of the Hudson as it was along the Delaware. Also, as nearly two decades had passed since the *Perseverance* was launched, the public might have been more open to the idea of traveling by steamboat.

Fulton was indebted to Fitch and others who had worked on the idea of the steamboat. He based his design on these earlier plans. When Fulton was in France a few years after Fitch, he might well have seen the plans that Fitch had left there. Fitch had clearly demonstrated that a steam-powered boat could work.

—*Dale Anderson*

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Shagena, Jack L. *Who Really Invented the Steamboat? Fulton's "Clermont" Coup*. Amherst, N.Y.: Humanity Books, 2004. Highly readable account of the work of several inventors and thinkers. Shagena gives useful background on patent law and steam power and carefully assesses the claims to primacy of eight inventors.

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See also: Oliver Evans; Robert Fulton; John Stevens; James Watt.

HENRY FORD

American industrialist

Although the popular image of Ford is associated with the early "Tin Lizzie" (Model T), the industrial world both in the United States and abroad recognizes him as the main pioneer of assembly-line mass production. His giant factories contributed not only to commercial car production but also to wartime needs, particularly for rapid production of B-24 bombers.

Born: July 30, 1863; Springwells Township (now Dearborn), Michigan
Died: April 7, 1947; Dearborn, Michigan
Primary fields: Automotive technology; business management; mechanical engineering
Primary inventions: Model T "Tin Lizzie" automobile; assembly line

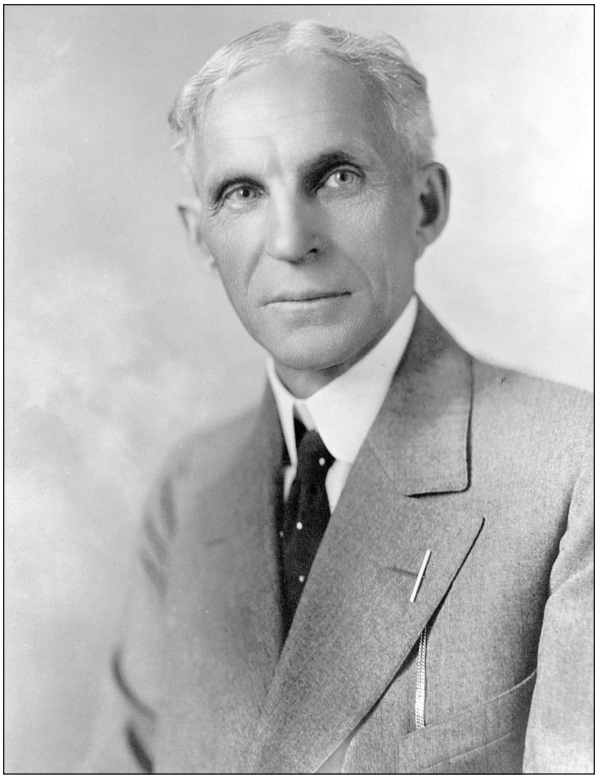
EARLY LIFE

Henry Ford's father, William Ford (1826-1905), was an Irish immigrant who married Mary Litogot, the daughter of Belgian immigrants. The couple settled on a farm west of Detroit, Michigan, in an area that is now the city of Dearborn. Henry was the eldest of five siblings born during the ten-year period between 1863 and 1873. His mother died when he was only thirteen years old. As a boy, he was not attracted to farm life, even though his father probably expected him to eventually take over the family's acreage. By the time Henry left the Dearborn area in 1879 to work as a machinist in Detroit, he had developed a local reputation for his ability to repair watches. His childhood interest in mechanical devices, however, soon drew him to the workhorse engines of the late nineteenth century: steam engines. When he married Clara Ala Bryant (1865-1950) in 1888, he had been employed by Westinghouse as an engineer (self-trained) responsible for maintenance of the company's steam engines. Within a few years, he changed over to another well-known pioneer firm, the Edison Illuminating Company, filling responsibilities there as chief engineer by 1893. It was apparent, however, that the thirty-year-old Ford wanted to dedicate himself to the emerging field of gasoline-powered internal combustion engines.

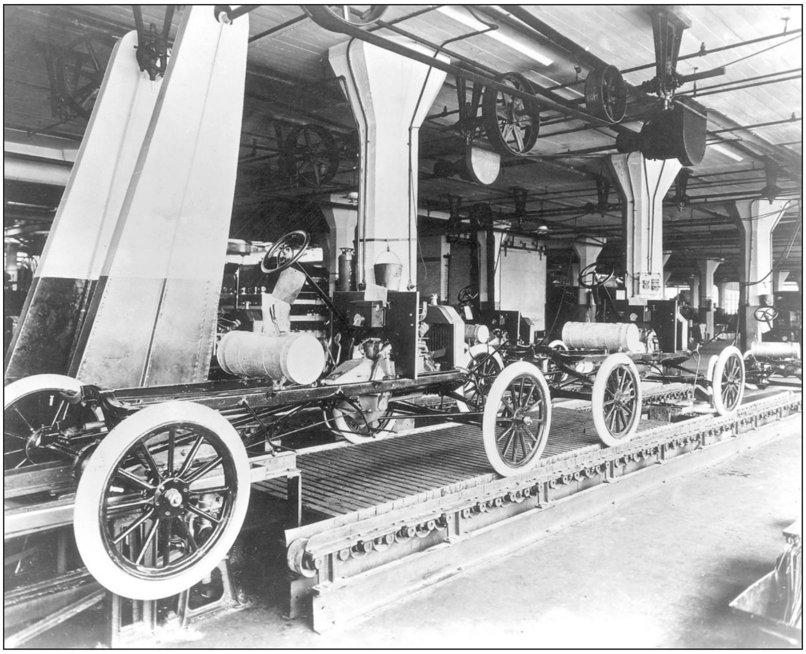
LIFE'S WORK

By 1896, Ford had succeeded in building his first gasoline motor-driven vehicle, the Ford Quadricycle. After Thomas Alva Edison himself encouraged him to perfect the Quadricyle, only three years passed before Ford sought capital backing from Detroit businessman William Murphy and cofounded a first, though not very successful, company, the Detroit Automobile Company. Even though the company folded in 1901, Murphy continued to support Ford's efforts, forming another short-lived company (this time bearing Ford's name). Ford's first real success, however, was only indirectly related to his experience building motor vehicles for commercial sale. It would come as he approached middle age and would associate the name Ford with the emerging competition for high-performance racing cars.

In 1902, one year before the independent Ford Motor Company was founded, Ford was involved in a partnership with a Detroit coal dealer, Alexander Malcomson, who was interested in Ford's original designs of racing cars. Ford's association with racing cars bore some of the attributes of his approach to marketing in later stages of his career. The young inventor not only drove his racing car in public demonstrations and made a fanfare each time a new speed record was set but also contracted one



Henry Ford. (Library of Congress)



Model T assembly line in the Ford Motor Company's factory in Highland Park, Michigan. (Library of Congress)

of the earliest symbols of car racing as a sport, Barney Oldfield, to tour the country, making certain that—even if onlookers would not be prospective buyers of racing cars—the name Ford would gain wide popular recognition. In short, when Ford turned his focus to the challenge of building motorcars for the general public, he had already begun to develop business skills that would characterize his entire career.

Ford knew, for example, that rapid expansion of passenger automobile production would require expansion of sales outlets for his cars. He thus pioneered a business method that eventually came to characterize the automobile industry as a whole: establishing franchise agreements that allowed private contractors to open Ford agencies in every major city in the United States. Very early on, Ford's Model T (nicknamed the "Tin Lizzie"), which began production in 1908, began to attract not only American but also foreign buyers. Channels for marketing would extend to Canada and Europe (starting in 1911, when an agency opened in Great Britain, and the 1920's, when cars were sold in Italy, France, and Germany). In 1927, Ford Motor Company began production of the Model A. By 1929, there were dealerships on every continent of the world.

Probably the most outstanding example of Ford's industrial production skills was the River Rouge Plant in Dearborn, Michigan. Construction of this plant complex, known locally as "The Rouge," took nearly a decade, between 1917 and 1928. The size of the complex surpassed all previous automobile production sites—covering a total surface of 1 by 1.5 miles and containing nearly one hundred buildings—and the site incorporated complementary infrastructure into its planning. Ford improved the factory's access to the Rouge River (and therefore to the Great Lakes themselves) by extensive dredging and built an internal network of railroad tracks so that company-owned trains could link all key facilities to points of out-shipment. At various stages of the company's development, Ford decided to diversify company assets by acquiring interests in companies involved in providing key raw materials, including rubber and steel.

Beyond Ford's accomplishments in the area of mass production of vehicles for private buyers, his factories played a major role during World War II. During World War I, Ford had built engines for airplanes that were just beginning to be used in combat and also produced antisubmarine "Eagle boats." The Ford plant at Willow Run, Michigan, became a major supplier for the U.S. war effort in World War II. The huge plant, together with an adjoining airfield, was constructed in 1941, specifically for the production of B-24 bombers. Its main building, in which an army of workers used rapid assembly-line procedures similar to techniques Ford had developed for automobile production, was reputed to be the largest enclosed factory area in the world. By 1944, the Willow Run installation was capable of producing over four hundred B-24s over a year's time. Following the war, ownership of the factory went to Kaiser Motors. It was later taken over by General Motors for production of specialized automobile components, while the wartime airfield at Willow Run continued to function for cargo flights.

Facets of Henry Ford's career less directly related to his world-famous skills as an industrial innovator should be noted. Ford seems to have been convinced that the labor union movement produced more negative effects than benefits for workers. His own company could claim that the variety of benefits and special programs offered in his shops (through a managerial branch called the Service Department) were proof that labor and factory owners could and should look after the best interests of both parties. This philosophy, however, was probably considered by labor unions as an atypical case that did not necessarily carry over to the automobile industry as a whole.

Attempts by the United Auto Workers (UAW) union to organize the Ford plants were staunchly opposed by Harry Bennett, the head of the company's Service Department in the late 1930's. Bennett gained a reputation for intimidating any workers who might lobby for a contract with the UAW. A bloody confrontation between union organizers and company security forces in 1937, known as the Battle of the Overpass, may have influenced Ford's son Edsel (who in 1919 had become president of Ford Motor Company) to try to convince his father to consider a collective-bargaining agreement. Ford senior held out until he was confronted, in the spring of 1941, with a successful UAW strike at the River Rouge Plant. Differences within the family, and apparently the insistence of Ford's wife, Clara, finally induced Henry to approve a contract with the UAW in June, 1941. The importance of this decision cannot be overstated. Ford Motor Company was the last Detroit automaker to recognize the UAW, and the contract turned out to be one of the most favorable union agreements for U.S. autoworkers. The timing of the agreement was also important: U.S. entry into World War II (and Ford's subsequent involvement in producing for the war effort) came only six months later. Edsel's death in 1943 would require that the family be unified in major decisions like the 1941 UAW contract. Edsel's son, Henry Ford II, succeeded as head of Ford Motor Company just as the war ended, guaranteeing this unity.

IMPACT

Ford and his company transformed American society by creating the assembly line, revolutionizing the nature of work. Ford's mass-production methods would serve as a model for a number of other basic industries both in the United States and abroad. His success in "cutting frills" in Model T production would have an important effect on business patterns. Ford's sales agencies became familiar sights in a number of key towns; investment by private businessmen to obtain such franchises would, in many cases, stimulate local economies throughout the country. Determined to make his automobiles accessible to the average American family, Ford introduced the inexpensive Model T in 1908, democratizing the automobile and dramatically changing American social patterns. Such changes ranged from extended commuting distances to new opportunities for recreation and vacations.

—*Byron Cannon*

THE TIN LIZZIE

A good part of the legend of Henry Ford and automobile manufacturing in the United States is based on the image of the Model T, popularly known as the "Tin Lizzie," produced between 1908 and 1927. Ford himself did not design the Model T. Instead, a team of company engineers put the original plans together. Although the Model T became the most famous Ford vehicle of the pre-World War II era (rivaled, no doubt, by the Model A that followed it), it had several nearly forgotten predecessors, including the original Model A (1903-1904), the Model N (1906-1908), and the Model S (1907-1909). There were also a number of models between A and S that never went to production.

A combination of factors made the Model T a success: its simple design lent itself to quality construction and reliability, and the price structuring made the car affordable to the average family. By the time production shifted to the new Model A in 1927, over fifteen million Model T cars had left the assembly line. Some of the essential features of the Model T included adoption of a single block to house the car's four cylinders (most early cars had individually cast sections), and a combination of three foot pedals (two for shifting, one for braking) and a side-mounted lever connected to the gear-changing process. There were two speeds forward and a reverse gear (the middle floor pedal). Another lever on the steering wheel controlled the inflow of gas through the throttle mechanism.

Starting a Model T involved turning the motor over manually through the use of a crank extending from the crankshaft through the front of the car. An example of the Model T's extremely simple engineering (a factor that helped Ford mass-produce the vehicle at low cost) was the choke mechanism. A simple wire came out of the base of the radiator, allowing the person cranking the motor to make fuel-injection adjustments with the free hand.

Tradition has it that Ford considered the new model introduced in 1927 to be such a dramatic departure from the Tin Lizzie that he decided to abandon the sequential alphabetical order of models used since the founding of his company, returning to *A*.

Further Reading

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See also: Carl Benz; George Washington Carver; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; John Boyd Dunlop; Thomas Alva Edison; Oliver Evans; King Camp Gillette; Charles Goodyear; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; André and Édouard Michelin; Ransom Eli Olds; Nikolaus August Otto; Stanford Ovshinsky; Sylvester Roper; Ignaz Schwinn; Charles E. Taylor; Felix Wankel; Alexander Winton.

Jay Wright Forrester

American electrical engineer

Forrester invented the memory system for digital computers called magnetic core memory, which was used from the early 1950's to the early 1970's. He also developed a simulation modeling method called system dynamics to understand and address complex issues in industry and society.

Born: July 14, 1918; Anselmo, Nebraska
Primary fields: Business management; computer science; electronics and electrical engineering
Primary inventions: Magnetic core memory; system dynamics

Early Life

Jay Wright Forrester was born on a cattle ranch in Nebraska in 1918. The ranch had no electricity. While he was in high school, he constructed out of old car parts a wind-driven, 12-volt electrical system that supplied power to the ranch. Growing up on the ranch gave him a practical and personal understanding of the concepts of economics such as supply and demand and the costs of running the ranch relative to changing prices. Other activities included herding cattle, even during blizzards. He obtained a scholarship to attend the Agricultural College in Nebraska, although he decided that continuing in agriculture was not for him. Instead, he attended the Engineering College at the University of Nebraska, where he majored in electrical engineering.

On graduating from the University of Nebraska, Forrester attended the Massachusetts Institute of Technology (MIT), which offered him a research assistantship for $100 per month. His mother knew about MIT because she had been a librarian for several years in a nearby town. At MIT, he worked for Gordon S. Brown, a pioneer in feedback control systems, helping to develop mechanisms for the control of gun mounts and radar antennas for use during World War II.

They constructed an experimental control unit for a radar of an aircraft carrier that directed planes against targets. The experimental unit was taken by the captain of the aircraft carrier USS *Lexington* to use on the carrier instead of waiting a year for production models. When the experimental unit stopped working after nine months, Forrester volunteered to go to Pearl Harbor to investigate the problem. In order to fix the unit, he had to ride the carrier into the invasions of Tarawa and the Marshall Islands. The Japanese managed to hit one of the *Lexington*'s propellers with torpedoes, but Forrester was not injured. This series of events allowed him to see how theory, research, and application were practically related.

Life's Work

Toward the end of World War II, Forrester began to work on an aircraft flight simulator at MIT. A model plane could be flown in a wind tunnel in the simulator to predict how the plane would fly before it was constructed. An analog computer was to be used for the calculations on the simulator, but it could not do the complex calculations rapidly enough. Between 1946 and 1951, Forrester and Robert Everett helped to design and construct the Whirlwind digital computer to perform the calculations. The Whirlwind computer was a 16-binary-digit, parallel computer that could perform about fifty thousand calculations per second, which made it about ten thousand times faster than mechanical computers. This computer allowed them to test circuit designs and the reliability of computers to improve on computers in the future.

Forrester saw the need to have a faster and more reliable digital memory, so from 1949 to 1953 he developed a magnetic core memory. By 1953, he had developed and installed the first parallel, high-speed, clock-driven computer with magnetic core memory in the U.S. Air Force's Semi-Automatic Ground Environment (SAGE) system. The Whirlwind and SAGE computers were financed by the military in order to be used in an air defense system to detect invading aircraft using radar and to potentially direct intercepting planes against the invaders. Many electronic computers were placed across the country and were interconnected to radar stations using communication lines.

In 1956, Forrester moved to the Sloan School of Management at MIT. He thought that it would be a challenge to apply his science background to problems in management, and he initially had a difficult time deciding what to do at the school until by chance he talked to someone at General Electric (GE). The administrators at GE were puzzled as to why their household appliance plants in Kentucky were sometimes working to capacity in three shifts, but then a few years later a large number of the workers had to be laid off. Forrester worked on a simulation to determine why this cycle occurred. He factored in the number of orders and employees, inventories, and decision-making policies with time. The hiring cycle was judged to be due to the way GE was organized rather than to changes outside the firm such as the number of units sold. This method of analysis was the beginning of what Forrester called system dynamics, which he used to study problems in industry, education, and the world social order.

MAGNETIC CORE MEMORY

In the early 1950's, Jay Wright Forrester discovered and developed magnetic core memory, which was used in the first parallel digital computers. Core memories increased the speed and reliability of computers compared to the analog computers of the 1940's. Each magnetic core memory unit had three sets of magnetic wires, called the X, Y, and Z wires. The wires allowed the core to be magnetically switched from a clockwise to a counterclockwise field, which relates to the on-off memory in today's computers. Some computers had more than 100,000 cores. Such core memories could be mass-produced effectively, and they were reliable and fast. For the first time ever, computer users could trust that large quantities of data could be used to calculate results. Magnetic cores were used in computers from the 1950's to the early 1970's.

Forrester intially had International Business Machines (IBM) produce the Whirlwind computer in 1952. It was used until the first Semi-Automatic Ground Environment (SAGE) computer was shipped to the Massachusetts Institute of Technology (MIT) in 1955. Both computers were used for the U.S. military's air defense. Many experts thought that the Whirlwind computer had limited use, but in fact it was built to test circuit designs and reliability so that other computers could be better constructed. The Whirlwind computer was a "walk-in computer," so named because it filled a 30-by-45-foot room, with racks of panels up to eight feet high. It used thousands of vacuum tubes that were redesigned to increase their life from 500 hours to 100,000 hours. The SAGE computer contained just over 135,000 magnetic cores, and the control circuits contained 776 vacuum tubes. Both MIT and IBM produced magnetic cores. IBM produced small batches of cores, whereas MIT produced the cores in large batches. IBM's 704 computer, brought to market in 1954, was the first mass-produced computer to use magnetic core memory. By the 1960's, transistors had replaced vacuum tubes.

When Forrester filed for a patent for magnetic core memory in 1951, he discovered that J. A. Rajchman at RCA had filed his patent for magnetic memory eight months earlier. Forrester, however, was the first person to develop magnetic cores. The lawyers from RCA argued that Forrester delayed too long in filing his application and that therefore RCA should get the credit and money from its patent. The Board of Patent Interference agreed in 1960. This decision was challenged in the courts by MIT. An agreement between MIT and RCA was reached in 1964 in which Forrester and MIT retained many of their important patent claims along with $13 million.

Forrester and graduate students from MIT then began to use computers to calculate the results that Forrester had previously calculated using paper and pencil. In 1958, Richard Bennett, a computer programmer, wrote programs for the calculations. Jack Pugh further improved these programs with his DYNAMO series. These programs were used for more than thirty years.

These calculations gave some insight into why some companies failed or stagnated. Often, problems were not due to the number of items sold, the capacity of filling orders, price, quality, or delay in deliveries, but rather were due to issues related to the top executives' leadership, character, goal creation, management structure, and past traditions.

In 1968, Forrester began applying system dynamics to urban problems. He collaborated with former Boston mayor John Collins on the urban dynamics approach, resulting in Forrester's controversial book *Urban Dynamics* (1969). For instance, they showed that, contrary to popular belief, building economical housing in the inner cities did not help to revive those areas; in fact, it was detrimental. Many experts, city officials, and black leaders in the inner city were outraged at this conclusion. According to Forrester, the main problem with building large housing projects was that it used up space in which jobs could be created and caused many additional unemployed people to move to the housing projects, resulting in more poverty. Indeed, tearing down low-income housing eventually led to job creation and income generation.

In the 1970's, Forrester began to apply system dynamics to global problems. In 1971, he published *World Dynamics*, in which he suggested that industrialization may pose a greater threat to world equilibrium than overpopulation. His work influenced the Club of Rome's *The Limits of Growth* (1972), a best seller that predicted the collapse of socioeconomic systems some time in the twenty-first century.

Forrester received the IEEE Computer Society Pioneer Award in 1982. In 1989, President George H. W. Bush awarded him and Robert Everett the National Medal of Technology. Forrester continued to publish papers on system dynamics into the 1990's.

IMPACT

Magnetic core memory was the standard for memory storage for twenty years. Although magnetic core technology was quickly replaced by semiconductor chips in the 1970's, it allowed for relatively high-speed digital computers in the 1950's and 1960's to be produced in quantity at low cost. Also, data input and programming were steadily advanced using the magnetic core computers instead of the old analog computers. Thus, the stage was set for the development of faster computer chips beginning in the 1970's.

System dynamics was initially used to model and solve problems with industry and cities, leading to applications in other areas, including global issues. Forrester later applied system dynamics to grade school through high school education. He continued to apply system dynamics to the U.S. economy, which, he concluded, undergoes a forty- to sixty-year cycle that includes economic slumps.

—*Robert L. Cullers*

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See also: Charles Babbage; Clifford Berry; Vinton Gray Cerf; John Presper Eckert; Bill Gates; Ted Hoff; Steve Jobs; Bob Kahn; An Wang; Konrad Zuse.

LÉON FOUCAULT

French physicist

Foucault made numerous discoveries and inventions important to the advancement of mathematics and astronomy. He invented the gyroscope and developed improved techniques in astronomical optics. He designed the Foucault pendulum, elaborated the sine law, and demonstrated the Earth's rotation.

Born: September 18, 1819; Paris, France
Died: February 11, 1868; Paris, France
Also known as: Jean Bernard Léon Foucault (full name)
Primary fields: Astronomy; mathematics
Primary inventions: Foucault pendulum; gyroscope

EARLY LIFE

Jean Bernard Léon Foucault (ZHAHN behr-NAHR lay-OHN foo-KOH) was born in Paris, France, on September 18, 1819. He was the son of Jean Léon Fortuné Foucault and Aimée Lepetit. He had a younger sister, Aimée Alexandrine Fortunée, and may have had a brother who did not survive. His father was a well-established Parisian publisher, but he suffered from ill health and retired from his profession not long after Léon was born. The family moved to Nantes, but his father's health did not improve and he died in 1829. Léon and his mother moved back to Paris.

Léon was a frail child with a serious vision problem: He was nearsighted in one eye and farsighted in the other. This gave him a rather bizarre appearance. He was very self-conscious and preferred to spend time alone. Hoping to give him an excellent education, his mother sent him to Collège Stanislas. Though he was very intelligent, he was a poor student. Consequently, his mother opted to have him educated at home by tutors.

As an adolescent, Foucault developed a penchant for making things, particularly intricate, sophisticated toys. He constructed a steam engine and followed this with a telegraph. Impressed with his manual dexterity, his mother decided that a career as a surgeon would be an excellent choice for him. In 1839, he entered medical school in Paris. Foucault did very well in his studies and attracted the attention of his professor Alfred Donné. However, when Foucault began his in-hospital training, disaster struck: He fainted at the sight of blood; this became a problem he could not overcome. He was left with little choice but to withdraw from medical school. However, Donné felt that Foucault's talent could still be useful in the field of medical science and made him his assistant—in a post that would not require him to be in contact with patients.

LIFE'S WORK

While he was a student at the Collège Stanislas, Foucault had become good friends with Hippolyte Fizeau. At about the same time that Foucault started working under Donné, he and Fizeau attended several lectures on photographic methods given by Louis Jacques Daguerre. The two friends began experimenting on their own and actually made improvements to the Daguerre's methods. Then, working for Donné, Foucault used his skills in photography to develop a method for taking photographs through a microscope. In order to take the photographs, Foucault needed to be able to illuminate the objects under the microscope. He devised a method for creating a very powerful electrical source of light to take the photographs. In 1845, with Donné, he published a course in microscopy presenting his work taking photographs through a microscope.

Léon Foucault. (Caltech Institute Archives)

Foucault’s Pendulum

As an astronomer and mathematician, Léon Foucault wished to demonstrate in a visible manner that the Earth rotates. While other scientists had concentrated on the time of the pendulum’s swing, he focused on the plane of the pendulum. He became convinced that he would be able to demonstrate the Earth’s rotation by using a pendulum with a special support. He designed a support that let his pendulum move in any direction without any resistance. On January 3, 1851, in the basement of his home, Foucault made his first experiment with such a pendulum. He constructed a pendulum by attaching a 1.98-meter-long wire to the ceiling of his basement. He had attached a five-kilogram bob to the end of the wire. In order to start his pendulum swinging from complete inertia, he tied the bob to the wall with a cotton rope. Next, he used a candle to burn through the rope. Unfortunately, the wire broke and ruined the experiment. On January 8, he again tried his experiment. This time the wire held, and within a half hour displacement of the pendulum was evident. He had mounted a pointer on the floor so that it furnished a point of reference.

At the invitation of François Arago, director of the Paris Observatory, Foucault repeated his experiment in the Meridian Room of the observatory before a large audience of scientists. For this experiment, Foucault constructed a pendulum that had an eleven-meter-long wire and used the same five-kilogram bob that he had used in his basement experiments. The longer wire enabled the pendulum to continue to swing for a longer period of time. Foucault’s demonstration was a resounding success. Then, he did yet another experiment with his pendulum. This one took place at the Panthéon in Paris and brought him worldwide recognition. The bob of the pendulum installed at the Panthéon weighed twenty-eight kilograms and was suspended from the dome of the building on a wire measuring sixty-seven meters in length. The pendulum’s plane rotated in a clockwise direction at a rate of 11° per hour. At the end of eight hours, the pendulum appeared to be swinging in a direction at a right angle to the original direction. It made a full circle in 32.7 hours. Physicists had already established that once a pendulum began to swing, it did not change its direction. Therefore, the Earth had to be rotating. Foucault’s pendulum experiment was the first indoor demonstration that proved the Earth’s rotation.

That same year, Donné, who was the scientific editor of the daily publication *Journal des Débats*, retired, and Foucault accepted his position. Although Foucault had no formal training in science, he was very successful as an editor. François Arago, a physicist and astronomer and director of the Paris Observatory, read Donné and Foucault’s book. He quickly contacted Foucault and Fizeau, asking them to take photographs of the Sun. In 1845, they successfully produced the first photograph of the Sun’s surface, which showed sunspots. Arago was enthusiastic about having them do other experiments for the Academy of Sciences, and he asked them to try to measure the speed of light in water. Foucault and Fizeau began a collaborative experiment but soon argued and went their separate ways. Working alone, Foucault developed a method for measuring the speed of light. He built a steam engine that drove a spinning mirror to make his proof. In 1850, using this device, he demonstrated that light travels slower in water than in air.

Next, Foucault turned his attention to the construction of a pendulum with a support that permitted it to move freely in any direction. He believed that such a pendulum would keep its plane of swing while Earth rotated beneath it. In January of 1851, he successfully constructed such a pendulum in his basement. Foucault immediately shared his success with Arago, who ask him to construct another such pendulum in the Paris Observatory. Foucault agreed and on February 3 successfully demonstrated his pendulum before an audience including the major scientists of the time. The same day, Arago presented Foucault’s paper on the pendulum to the Academy of Sciences. The paper included Foucault’s sine law ($T = 24/\text{sine}\ q$), which he presented without proof. In Foucault’s sine law, the T stands for the time in hours necessary for the pendulum to return to its original position; q represents the latitude of the place where the experiment is performed. This formula proposed that the pendulum would require twenty-four hours to return to its original position at either the North or South Pole and that it would not rotate at the equator.

Foucault continued his work to invent instruments that would demonstrate the motion of the Earth. He invented the gyroscope, which was later used for aircraft navigation. Although he enjoyed widespread renown, his only source of income was his post as editor of the *Journal des Débats* until 1852. As a result of the coup d’état on December 2, 1851, in which Napoleon Bonaparte took absolute power and then declared himself emperor as Napoleon III, Foucault received a special appointment. Napoleon III was himself an amateur scientist and was highly impressed by Foucault’s accomplishments, all the more so because Foucault had no formal training in science. The emperor created especially for him the post of Physicist Attached to the Imperial Observatory. Napoleon III had renamed the Paris Observatory the Imperial Observatory and appointed Urbain Le Verrier, a gifted astronomer, as director. Foucault invented several telescopes with special features and many new instruments that were used at the observatory. He continued to do experiments and make important discoveries. In one of his experiments, he succeeded in measuring the speed of light with an accuracy within one-half of one percent. This experiment achieved the most precise measurement of the speed of light of any experiment done up to that time.

In 1860, Foucault and Le Verrier went to Spain to observe the eclipse of July 18. Using his talents as a photographer and as an astronomer, Foucault obtained a photograph of the event. After his return to France, Foucault received several honors. In 1862, Napoleon III made him an officer of the Légion d'Honneur. He was elected to the Bureau des Longitudes and made a fellow of the Royal Society of London as well as a member of the German Academy of Sciences Leopoldina. Although Foucault had repeatedly proven himself as a scientist by his inventions, experiments, and discoveries, for most of Foucault's career the academically educated community of scientists was reluctant to recognize him as a scientist because of his lack of formal academic training in science. Finally in 1865, he was elected to the French Academy of Sciences.

In October of 1867, Foucault began experiencing health problems, including numbness in his hands. His mother made every effort to bring about his recovery, but the illness worsened quickly. It has been speculated that the chemicals he had used in experiments during his life, especially mercury, were the cause of his illness. He died on February 11, 1868, in Paris.

IMPACT

Although Foucault had no formal training in science and was often shunned by the academically trained scientists of his day, Alfred Donné, François Arago, and Napoleon III recognized his exceptional talent. Their appreciation of his work enabled him to make his discoveries and inventions known publicly. As Donné's assistant, he developed and published techniques for taking photographs through a microscope that opened new possibilities in medical research.

Using instruments already developed by other scientists such as a spinning mirror and an achromatic lens, he measured the speed of light in water and verified that light travels slower in water than in air, thus establishing that light speed varies according to the medium through which it travels. Foucault solved a problem that had perplexed scientists for twelve years.

The greatest impact of Foucault's work was made by his pendulum demonstrations, which allowed people to see proof that the Earth rotates. His gyroscope also contributed to demonstrating the Earth's motion. Although the gyroscope was not particularly useful in Foucault's time beyond its use in his demonstration, it later played and continues to play an important role in airplanes and in guiding telescopes.

—*Shawncey Webb*

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See also: Charles Stark Draper; Elmer Ambrose Sperry.

BENJAMIN FRANKLIN

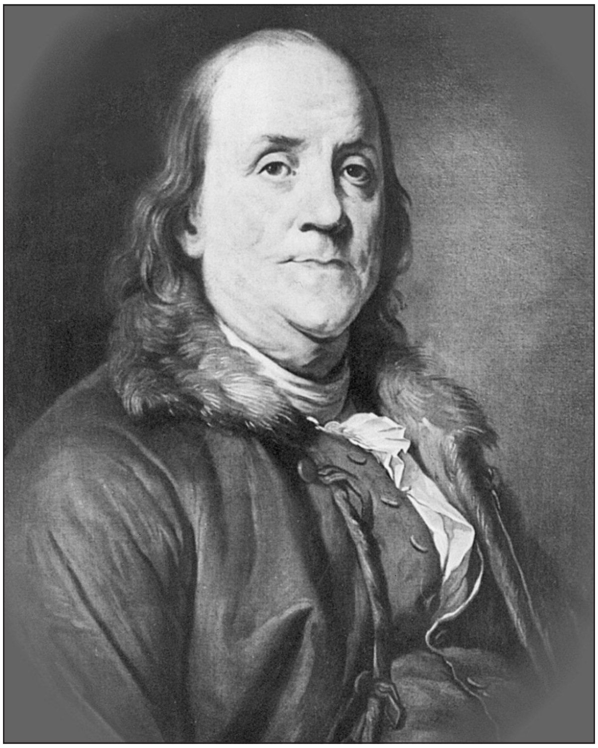
American scientist

Franklin's many practical inventions and improvements contributed to the greater safety and comfort of human beings throughout the world. His unflagging inventiveness extended to social forms and processes, as well as mechanical and electrical devices.

Born: January 17, 1706; Boston, Massachusetts
Died: April 17, 1790; Philadelphia, Pennsylvania
Also known as: Alice Addertongue; Le Bonhomme Richard; Silence Dogood; Harry Meanwell; Poor Richard; Richard Saunders; Timothy Turnstone
Primary fields: Electronics and electrical engineering; household products; mechanical engineering; physics
Primary inventions: Lightning rod; Franklin stove

EARLY LIFE

Benjamin Franklin was the youngest son (and fifteenth child) of Josiah Franklin, an English immigrant to Boston, and Abiah Folger, Josiah's second wife. The family was poor, and young Benjamin's formal education ended when he was ten years old. At the age of twelve, he was apprenticed to his brother James, who began printing *The New-England Courant* in 1721. Benjamin honed his writing skills and, at the age of sixteen, managed to anonymously publish in his brother's newspaper a popular series of satiric letters under the pseudonym Silence Dogood. When Benjamin finally revealed that he was the author of the prose, James was not amused.



Benjamin Franklin. (Library of Congress)

Franklin left the apprenticeship and moved to Philadelphia to practice the printing trade. He spent two years in England (1724-1726) before returning to Philadelphia. Through his constant efforts at self-improvement, his ability to form valuable relationships, and his good judgment in business and politics, he prospered and became an eminent citizen and, eventually, a public figure.

His abilities as a writer made his *Poor Richard's Almanack* (1732 and after) a perennial bestseller, afforded him considerable influence over popular opinion, and enabled him on occasion to serve as the voice of Pennsylvania, and eventually of his country. This, along with his other work as printer and publisher, made Franklin a wealthy man, allowing him to retire in early middle age (at forty-two, in January, 1748) and pursue his scientific and philanthropic interests. His eminence in these areas reinforced his value as a political theorist and an effective practical organizer.

Franklin's intellect combined scientific insight, mechanical cleverness, and a general knack for useful innovations in process design. His perpetual impulse to make things better also inspired efforts to improve scientific and political communication and education, through the founding of associations devoted to intellectual conversation and self-improvement. Certainly, these associations contributed to the dissemination of both public knowledge and the scientific spirit and encouraged the nurture of inventiveness in subsequent generations.

In 1731, at the age of twenty-five, he founded the Library Company, the model for subsequent libraries in the American colonies. (He also influenced the development of forces for fire and police protection.) In 1749, he published a pamphlet urging the establishment of a nonsectarian educational academy, which began functioning two years later (and eventually, in 1791, became the University of Pennsylvania). Soon thereafter, he helped to raise money to found a hospital, in the process inventing the idea of the private/public matching grant.

LIFE'S WORK

Franklin considered the communication and application of useful knowledge almost as important as its discovery. In 1743, he published a pamphlet proposing what became in the following year the American Philosophical Society, an organization devoted to the communication of knowledge concerning, as Franklin explained, "all philosophical Experiments that let Light into the Nature of Things, tend to increase the Power of Man over Matter, and multiply the Conveniencies or Pleasures of Life"—as succinct a statement of the credo of an inventor as one could want.

Biographers of Franklin routinely comment on the way his observations of everyday life lead to his asking revealing questions, prompted partly by curiosity and partly by a constant desire to do good to his fellow man—or at least, not to waste time or money. In his *Autobiography* (1793), Franklin provides insight into his scientific way of thinking when he describes listening to an outdoor preacher:

> I had a curiosity to learn how far he could be heard, by retiring backwards down the Street towards the River, and I found his Voice distinct till I came near Front-Street. . . . Imagining then a Semi-Circle, of which my Distance should be the Radius, and that it were fill'd with Auditors, to each of whom I allow'd two square feet, I computed that he might well be heard by more than Thirty-Thousand. This reconcil'd me to the Newspaper Accounts of his having preach'd to 25,000 People in the Fields, and to the ancient Histories of Generals haranguing whole Armies, of which I had sometimes doubted.

Though his mathematical sophistication may have been limited, Franklin in such passages clearly demonstrates his essentially quantitative attitude, questioning everyday experience and answering those questions through experiment and measurement. He then connects the results of his inquiry to reflection on other claims about reality (past and present). Franklin brought this tendency to question, measure, and explain to situations throughout his long life, producing innumerable practical inventions and innovations—some based on physical or mechanical novelties, and others involving emendations in the design of social processes.

The word "first" is constantly attached to Franklin's name, and the breadth of his scientific interests and the diversity of his practical innovations can be seen throughout his life. Even as a child and young man, he devised improvements in the technique and technology of swimming (1725 and earlier). He introduced the manufacture of printing type and the copperplate press in America (1728). He reflected on the track of storms and laid the foundation for the science of weather prediction (1743 and after). He developed a new kind of stove (1744). He speculated about the implications of population (1751). He introduced an improved urinary catheter (1752). He improved the lighting of streets (1757 and after). He investigated the principles of refrigeration (1758). He invented a new musical instrument made out of glass, the "armonica," for which Wolfgang Amadeus Mozart and Ludwig van Beethoven wrote compositions (1762). He promoted spelling reform and investigated lead poisoning (1768). He studied the physiology of exercise (1772) and the operation of the Gulf Stream (1775). He improved and promoted the first copying machine (1780), and he developed a long, mechanical arm for reaching up to shelves (1786).

The preeminent example of Franklin's scientific originality was his pursuit of experimentation in the fledgling field of electricity. Here he was able to take up a sideshow curiosity and develop it in ways that impressed upon a worldwide audience its basic scientific importance. In 1743, Franklin witnessed in Boston a performance by a traveling Scottish "electrician," Archibald Spencer. He was fascinated and before long began a series of experimental investigations concerning electrical phenomena.

His early retirement from the printing business, in 1748, afforded him more time to pursue his "philosophical" interests. His researches into electricity were made public through letters in 1750 and appeared as a small book in 1751 under the title *Experiments and Observations on Electricity*. Franklin's work led to theoretical insight as fundamental as the law of conservation of charge that, in the judgment of the distinguished historian of science I. Bernard Cohen, "must be considered to be of the same fundamental importance to physical science as Newton's law of conservation of momentum." It also led to practical applications as influential as the lightning rod and the electric battery. The terms "battery," "conductor," and "positive" and "negative" charge in an electrical application were coined by Franklin.

Franklin's systematic study of the similarities between electrical sparks and lightning (and his proposals for an experimental test) excited international interest, especially in France, where Thomas François d'Alibard conducted electricity from lightning in May of 1752. (Franklin's own famous kite-flying experiment—about which there has been some minor controversy because of his tardiness in announcing it—occurred in June of 1752, before he learned of the French success.) Growing out of these inquiries was the most practical, and the most famous, of Franklin's inventions, the lightning rod, which overnight transformed a terrifying aspect of nature's power into a manageable risk.

The Lightning Rod

In June, 1752, Benjamin Franklin performed (few now doubt) his famous kite experiment, to confirm the electrical nature of lightning; in October, he published a letter describing the experiment. The following year, in his almanac *Poor Richard Improved*, a brief essay, "How to secure Houses, &c. from Lightning," described a simple method of protection:

> Provide a small Iron Rod . . . of such a Length, that one End being three or four Feet in the moist Ground, the other may be six or eight Feet above the highest Part of the Building. To the upper End of the Rod fasten about a Foot of Brass Wire, the Size of a common Knitting-needle, sharpened to a fine Point; the Rod may be secured to the House by a few small Staples. If the House or Barn be long, there may be a Rod and Point at each End, and a middling Wire along the Ridge from one to the other. A House thus furnished will not be damaged by Lightning, it being attracted by the Points, and passing thro the Metal into the Ground without hurting any Thing. Vessels also, having a sharp pointed Rod fix'd on the Top of their Masts, with a Wire from the Foot of the Rod reaching down, round one of the Shrouds, to the Water, will not be hurt by Lightning.

The first lightning rods were erected in Philadelphia in the summer of 1752, and soon the idea caught on internationally. Franklin's fame spread as the discoverer of the nature of lightning (to the German philosopher Immanuel Kant, he was a "new Prometheus"), as the leading theorist of electricity, and most of all as the inventor of the lightning rod—"the Electrical Philosopher, the American Inventor of the pointed Rods."

The lightning rod captures the essence of Franklin's inventiveness: on one hand, based on a fundamental physical insight, which has secured Franklin's reputation as the grandfather of all the applications of electricity that were soon to follow and transform the world; on the other hand, eminently practical, with an evident, immediate, and profound impact on everyday life. As the leading student of Franklin's scientific work, I. Bernard Cohen, observes, "Although men of science had repeated [Francis] Bacon's statement that knowledge of nature would lead to power and control of nature's forces, there had never been a major example of this process until Franklin's invention of the lightning rod."

Undue credit was natural in the case of a man so renowned as an inventor. Already in his autobiography he notes that some people had mistakenly attributed to him the idea of public street lighting. In fact, he points out, he merely improved street lighting, with respect to both illumination and cost. By replacing globe street lamps with better ventilated, four-paneled lamps, he was able to improve airflow, and so prevent rapid darkening, as well as make damaged glass easier and cheaper to replace. Similarly, he is often said to have invented the idea of daylight savings time, though in fact he seems merely to have suggested in jest that Parisians could save a lot of money by "using sun-shine instead of candles."

In the case of what is sometimes considered his best-known invention, the "Franklin stove," the facts are complicated. Traditional fireplaces and stoves allowed much of the heat to escape up the chimney. Ever prone to remedy waste and needless expense, Franklin in 1744 produced a new kind of stove, which he called the "Pennsylvania fire place," to improve household heating.

Historians have questioned the stove's effectiveness, with Samuel Edgerton remarking that history has ironically "decided to attach Franklin's name to every kind of house-heating device except the ones he actually invented." However, Franklin in his autobiography recalls declining a lucrative patent for the invention of the stove, which reflected his characteristic attitudes to his inventions. In a letter of 1777, he declares: "I have no private Interest in the Reception of my Inventions by the World, having never made nor proposed to make the least Profit by any of them."

Even late in life, Franklin's habit of reflecting upon everyday experience and suggesting improvements persisted. In 1784, at the age of seventy-eight, finding it inconvenient to wear one pair of eyeglasses for reading and another pair for distance, he had both lenses appropriately cut and fitted together in a single frame, thus creating bifocals (he called them "double spectacles"). In the early 1780's, Franklin helped negotiate peace with Great Britain, and in 1787 he played a crucial role at the Philadelphia Convention, which produced the United States Constitution. In the late 1780's, he campaigned against slavery, and in 1790, at the age of eighty-four, he died. His incomplete and posthumously published account of his life became the most famous American autobiography of all time, as well as the model for many subsequent self-help books.

IMPACT

A quintessential Enlightenment figure, Franklin engaged throughout his life in both self-creation and self-promotion, combining private interest with an active concern for the public weal. His many important inventions and discoveries were bestowed freely on his fellow citizens and humanity at large, and the impact of many of them has been wide-ranging and long-lasting. As the Nobel Prize-winning chemist Dudley R. Herschbach wrote of Franklin near the end of the 1900's, "His work on electricity was recognized as ushering in a scientific revolution comparable to those wrought by Newton in the previous century or by Watson and Crick in ours."

Franklin's fame as scientist and inventor ultimately played a central role in his country's military fate. As historian Gordon Wood observes, "His crucial diplomacy in the Revolution makes him second only to Washington in importance." As ambassador to France during the revolution, Franklin was uniquely qualified to win support for the American cause. "The French mission," his biographer Stacy Schiff writes, "would prove the most inventive act in a life of astonishing inventions." He was esteemed by the gentlemen (and the ladies) of France, for his wit and his character, and as the heroic discoverer of the secrets of lightning and electricity. Without Franklin's political efforts in France, America might have been stillborn as a nation. Moreover, without his social inventiveness in the period of constitutional development during the decade following the revolution, America might not have survived its infancy. When biographers call him the first American, or even the inventor of America, the exaggeration is slight.

—*Edward Johnson*

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See also: Karl Ferdinand Braun; Robert Fulton; Joseph Henry; Ewald Georg von Kleist; Pieter van Musschenbroek; Joseph Priestley; Benjamin Thompson; Alessandro Volta.

JOSEPH VON FRAUNHOFER

German glassmaker, physicist, and optician

Fraunhofer developed a method for measuring the index of refraction of a piece of glass, which allowed the production of excellent optical equipment. He also developed the diffraction grating, an optical component that disperses white light into different wavelengths.

Born: March 6, 1787; Straubing, Bavaria (now in Germany)
Died: June 7, 1826; Munich, Bavaria (now in Germany)
Primary fields: Manufacturing; optics
Primary invention: Lenses; spectrometers; diffraction grating

EARLY LIFE

Joseph von Fraunhofer (FROWN-hoh-fur) was the eleventh child of Franz Xaver Fraunhofer, a master glazer. Seven of the children born to Franz died at an early age. Joseph lost his mother when he was ten and his father at age eleven. At age twelve, he was apprenticed to a master mirror maker in Munich, P. A. Weichselberger. In addition to the work in the glass shop, Fraunhofer had to do housework and kitchen duties, and he was not allowed to attend the Sunday school for poor boys.

In 1801, the workshop caved in, killing some of the occupants, but Fraunhofer was rescued. Maximilian IV Joseph, prince-elector of Bavaria, was at the scene of the disaster. He noticed Fraunhofer and gave the boy money. Another person who noticed him was Joseph Utzschneider, an instrument maker who had an interest in optics. Utzschneider gave Fraunhofer books on optics and talked to him about the subject. Weichselberger was forced to allow Fraunhofer to attend Sunday school, but he still did not allow him the freedom to study.

In 1804, Fraunhofer used his money from the prince to buy his freedom from Weichselberger. He also bought a glass-cutting machine and a grinding machine. With these devices, he tried to start a business that also included drawing, engraving, and printing business cards. His business did not earn enough money, so he returned to Weichselberger's employment as a journeyman. In 1806, Utzschneider hired Fraunhofer as a glass polisher at the Mathematical-Mechanical Institute of Reichenbach, Utzschneider and Liebherr.

LIFE'S WORK

Fraunhofer began designing and making lenses at the optical firm. He found that striations could not always be seen with the eye but could be seen in polarized light. The polarizer that he produced allowed him to check glass more carefully than before. The lack of available quality glass led the firm to buy a glass factory in Benediktbeuern. Fraunhofer was made a junior partner and put in charge of the factory. Working with a master glassmaker, Pierre Louis Guinand, Fraunhofer experimented with different mixtures of materials, cooling rates, mixing procedures, and any other variable that they thought might affect the glass.

Because polishing the lenses was so important, Fraunhofer designed and built machines that would polish the lenses correctly, even when operated by an unskilled workman. He also made a spectrometer, with which he could measure the refractive index of prisms cut from different pieces of glass. The refractive index can be calculated by measuring the coefficient of refraction. Fraunhofer used these values to ensure that all the glass in a batch had the same refractive index. The values were also important in producing achromatic lenses, which allow a telescope or other optical instrument to have both the red and the blue wavelengths focused at the same place. Achromatic lenses are made by combining two lenses with compatible refractive indexes.

While doing this work, Fraunhofer usually used a candle as a light source. One day, he used sunlight and found that there were black lines in the spectrum of light. (It is now known that these are wavelengths of light absorbed by gases in the outer atmosphere of the Sun.) Some of these lines were very intense and were assigned letters by Fraunhofer. As the equipment evolved and improved, he found as many as 574 individual lines. A few of the dark lines had been discovered years earlier by William Hyde Wollaston, but Fraunhofer was not aware of the discovery. This was a source of embarrassment to Fraunhofer when he was told about it. Although tens of thousands of these lines have since been charted by others, they are still called Fraunhofer lines.

Fraunhofer studied the light from the Moon and planets and found that it produced the same pattern as that of sunlight. When he used light from other stars, he found a different set of lines. He made no statement concerning the meaning of the different lines, but he did report his findings to the Bavarian Academy of Sciences. Using certain lines as markers, he was able to measure the index of refraction accurately by two orders of magnitude. This helped him to build the finest lenses in the world. The Mathematical-Mechanical Institute made a full range of optical devices, including telescopes, binoculars, precision spectrometers, magnifying glasses, spectacles, microscopes, and opera glasses. Fraunhofer also measured the sensitivity of the human eye to different colors and found that humans have chromatic aberrations. People do not see all the colors equally. He corrected for this fact in his lenses.

The greatest instruments made by the institute were the astronomical refracting telescopes, which were mounted on equatorial mounts. Designed by Fraunhofer, these mounts were turned by a gravity clock so that a star stayed in the view of the telescope instead of drifting out of sight as the Earth turned. The instruments made by Fraunhofer's design were the best telescopes made at that time and for many years afterward. In 1819, the institute moved to Munich.

Fraunhofer also studied diffraction. When light travels through a slit and then collides with an object, it seems to bend around the object. In fact, wavelengths add to or subtract from one another to form bright and dark spots. Fraunhofer eventually developed a grating comprising 260 close parallel wires that would disperse light into its spectrum more effectively than individual slits.

Fraunhofer's work earned him fame. He was accepted into the Bavarian Academy of Sciences as a corresponding member in 1814. A corresponding member cannot attend meetings, but in 1821 he was allowed to attend meetings as a visiting member. Several scientists were against his becoming a member of the academy because he had no formal education. Many felt that he was only a technician, not a true scientist. The University of Erlangen awarded him an honorary doctorate in 1822 and King Maximilian I made him a salaried professor in 1823. Fraunhofer was knighted in 1824, adding the honorific "von" to his name.

Many glassmakers died young because of the toxic metals and vapors involved in their work. When Fraunhofer caught a cold in September of 1825, he could not recover even though he spent months in bed. He died of tuberculosis in the following June.

IMPACT

By building the best astronomical telescopes up to that time, Fraunhofer opened up more of the universe to astronomers. His mount that moved with the stars was a new innovation for astronomy. One telescope built for the Russian Dorpat Observatory enabled Russian astronomers to catalog more than two thousand new double stars. Some of the telescopes built by his methods are still in use today.

Fraunhofer also helped transform optical instrument making from an art into a science. His index of refraction measurements was not only used to design lenses but also used to refine methods of the production of lenses. Unfortunately, the science of making optical instruments was such a guarded secret that much of what Fraunhofer knew was never written down and died with him.

Fraunhofer's work on diffraction was of such importance that diffraction in parallel rays is now called Fraunhofer diffraction. (He used the Sun's rays, which may be considered parallel.) His work on diffraction led him to build the first diffraction grating of parallel wires, which produced a dispersed spectrum. Later, he built other gratings of differing widths. With these he measured the wavelengths of the Fraunhofer lines and specific colors. He also built reflection gratings. He used a diamond bit to etch a grating with ten thousand parallel lines per inch.

The discovery of Fraunhofer lines was actually the first step toward spectrometry. Science now uses sev-

DIFFRACTION GRATING

A diffraction grating is an optical component that disperses light into a spectrum. A grating may be either transmission or reflection, depending on whether it is transparent or mirrored. The grating is lined with close, equidistant, parallel grooves. As the light hits the grooves, its wavelengths constructively or destructively interfere, resulting in the separation of the components of light. Each color of the spectrum represents a different wavelength. Violet is seen closest to the light source and red is farthest away. The spectrum group closest to the center is known as the first-order spectrum. The closer the lines of the grating, the more dispersed the spectrum.

Often, diffraction grating is the method of choice when light needs to be dispersed into a spectrum. A diffraction grating is used as a component of a monochromator to isolate the desired wavelength of light. Diffraction gratings are also used in colorimetry, metrology, laser optics, and infrared and Raman spectroscopy. Diffraction grating can be demonstrated by reflecting sunlight off a CD or DVD onto a white wall. In nature, peacock feathers, mother-of-pearl, and butterfly wings exhibit the effects of diffraction grating.

eral types of spectrometry, but Fraunhofer was the first to make accurate measurements of wavelengths, establishing one of most important methods of element detection.

—*C. Alton Hassell*

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See also: Roger Bacon; George R. Carruthers; Sir William Crookes; Galileo; Christiaan Huygens; Zacharias Janssen; Hans Lippershey; Bernhard Voldemar Schmidt.

HELEN M. FREE

American chemist

Free developed new medical testing procedures, including an easy-to-use, inexpensive dipstick test that made it possible for diabetics to check their own blood glucose.

Born: February 20, 1923; Pittsburgh, Pennsylvania
Also known as: Helen Mae Free (full name); Helen Mae Murray (birth name)
Primary field: Chemistry
Primary invention: Dipstick blood sugar test

EARLY LIFE

Helen Mae Murray was born in Pittsburgh, Pennsylvania, on February 20, 1923. She was the daughter of James Summerville Murray, a coal company salesman, and Daisy Piper Murray. When Helen was six years old, her mother died in an influenza epidemic. Helen began her education in the Youngstown, Ohio, public schools and then attended high school in Poland, Ohio, a suburb of Youngstown, graduating in 1941. She so admired a high school English teacher that she planned to follow in her footsteps, majoring in English in college and eventually teaching English and Latin to high school students. Helen decided to attend the College of Wooster, a small but distinguished liberal arts school, where she had attended a summer camp sponsored by the Presbyterian church.

After Murray's dormitory housemother pointed out that there was likely to be a shortage of scientists because so many men had left school to serve in World War II, Murray made a fateful decision: She changed her major to chemistry. It was a subject she liked and also one in which she excelled. At the end of her freshman year, she was awarded the William Z. Bennett Prize in Chemistry. During her senior year, she applied for a research fellowship at the Mellon Institute in Pittsburgh; meanwhile, she was interviewed by the head of quality control at Miles Laboratories in Elkhart, Indiana, which was the American subsidiary of Bayer. As her graduation date approached, she had had no response from Mellon. Therefore, though she would have preferred research to quality control, Murray decided to accept the position offered her by Miles, and she began work there shortly after her graduation from Wooster in May, 1944. A few weeks later, she was accepted by Mellon. Though she kept pressing her boss at Miles to give her a research assignment, for the next two years she was kept busy with quality control and with the development of procedures. Once the war ended, however, Miles embarked on new research projects, and Murray was at last able to fulfill her dream.

LIFE'S WORK

Among the new scientists hired to implement Miles Laboratories' programs was Alfred H. Free, a native of Ohio with a doctorate in biochemistry from Western Reserve University in Cleveland, Ohio. During the war, Free had worked on a process for transmitting blood plasma to field hospitals and had also contributed to the development of antibiotics. When Murray learned that the biochemists had a research position open, she set up an interview with Free. He hired her on the spot, and they began working closely together. It was not long before their professional relationship became a personal one, and on October 18, 1947, Murray and Free were married. During the next five decades, they would collaborate on important research projects, developing new procedures for medical testing. They would also have six children—Eric, Penny, Kurt, Jake, Bonnie, and Nina.

Helen Free is best known for her role in the development of the dipstick, a new method of urinalysis that made self-testing for diabetes possible. After their product Clinistix appeared in 1956, the Frees continued their work, refining the product so that one dipstick could be used to test for a number of different substances in urine. Their studies led to the publication in 1975 of the book *Urinalysis in Clinical Laboratory Practice*, which was recognized as a definitive work on the subject. However, the Frees did not limit their research to testing for diabetes; they also sought ways to utilize self-testing for other diseases. The fact that Helen Free received seven patents for clinical laboratory tests indicates the level of her achievements.

Meanwhile, Helen Free was steadily assuming more responsibilities at Bayer. In 1976, she became director of specialty test systems. In 1978, after receiving a master's degree in management/health care administration from Central Michigan University, she became director of marketing services in the research products division. After retiring in 1982, she remained a consultant to the firm, now known as Bayer Diagnostics. Until 1996, she also remained a member of the adjunct faculty at Indiana University in South Bend, where she had taught for twenty-one years.

In 1980, Free was awarded the Garvan Medal from the American Chemical Society (ACS), an annual award

DIPSTICKS FOR URINALYSIS

Working together, Helen M. Free and Alfred Free invented the urine dipstick—a simple, economical way to test for glucose in the urine of diabetic patients. A tablet called Clinitest had been developed by Miles Laboratories before the Frees became involved in the project. One of these tablets would be dropped into a test tube containing a urine sample, and the presence of glucose would be indicated by a color change in the liquid. The Frees experimented with the tablets, refining their chemical content. Inspired by the success of this process, they decided to apply it to other diseases. Since Hepatitis A was a major health problem, they made a tablet that could detect bilirubin in urine, thus signaling the presence of Hepatitis A. However, the Frees were determined to work out a simpler process, one that would not involve test tubes. They decided to drop the urine onto a small mat made from a material that would absorb the urine, leaving the bilirubin on the surface. The tablet was then dropped onto that mat. If Hepatitis A was present, a colorful ring would appear on the mat.

According to Helen Free, it was this use of the mat in the Ictotest process that prompted her husband to think of an improvement on Clinitest. If a piece of paper could be impregnated with the same chemicals that the tablet contained, then one could simply drop urine onto the paper and observe the results. It then occurred to the Frees that the paper could be cut into strips, so that instead of using a dropper, one could simply dip a test strip into the urine. Along with the test strips, there would be detailed instructions specifying the length of time that the strip should remain immersed in the urine, as well as a color chart that would enable doctors, hospitals, and the patients themselves to obtain the results of the tests immediately. This new product for the testing of urine glucose, which was given the name Clinistix, went on the market in 1956. Next, the Frees looked for a way to combine several tests on a single strip by using a barrier between the various reagents. In 1981, they introduced Multistix, which had ten different urinalysis tests on a single strip.

The Frees' invention revolutionized the treatment of diabetes by making it possible for tests to be conducted outside the laboratory. It was recognized almost immediately that self-testing kits were convenient as well as inexpensive for use by doctors and by hospitals. It soon became evident that patients could do their own testing. The fact that Clinistix proved to be so reliable made self-testing an acceptable practice. As a result, self-tests were developed in a great many different areas. Among the most common self-tests are those that determine ovulation or pregnancy and those that use stool samples to screen for colorectal cancer.

that recognizes distinguished service to chemistry by women. That same year, she received a Distinguished Alumni Award from the College of Wooster. Both that school and Central Michigan University awarded her honorary doctor of science degrees. In 1995, the Frees' collaborative efforts brought them the Laboratory Public Service National Leadership Award. Helen Free was inducted into the Engineering and Science Hall of Fame in 1996 and the National Inventors Hall of Fame in 2000.

Early in her career, Free became active in the ACS, where her primary goal was to make the public aware of the important role that chemistry plays in everyday life. From 1987 to 1992, she chaired the National Chemistry Week Task Force, and she also founded a group that worked to establish an International Chemistry Celebration. In 1993, Free was the first person without an earned terminal degree to be elected president of the ACS. During her tenure, she spoke on the subject of outreach to more than one hundred local sections of the ACS and also was frequently interviewed by the news media, emphasizing the importance of chemistry in the modern world. In 1995, she was the first recipient of an award established in her honor by the American Chemical Society, the Helen M. Free Award for Public Outreach.

Alfred Free passed away in 2000. Though Helen was now in her late seventies, she continued to be active in promoting the cause she had embraced.

IMPACT

Helen and Alfred Free's invention of the dipstick made it possible for diabetes tests to be conducted outside the laboratory—in doctors' offices, for example, and even by patients themselves. The dipstick process had a number of advantages: It was inexpensive; the results were available immediately; and patients who did their own testing could have much more control over their own lives. Though dipsticks were originally developed for use in diabetes testing, the invention was increasingly used for other diseases. Moreover, the acceptance of the concept of self-testing has radically changed the concept of medical care. Patients can now take much of the responsibility for their own treatment, a change that most have welcomed.

Helen Free's achievements as an inventor enabled her to become an influential advocate for her own field of chemistry and, more generally, for science and mathematics. Appalled by what she saw as the neglect of those subjects in the classroom, she not only publicized their importance by being involved in awareness programs such as National Chemistry Week, National Science and Technology Week, and National Medical Laboratory Week but also took her message into communities, where she spoke to civic groups and visited schools, working personally with both students and teachers. Free's goal was to inspire young people to dedicate their lives to scientific research, so that they might some day make significant medical discoveries or develop processes that significantly improve medical treatment.

—Rosemary M. Canfield Reisman

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See also: Marie Anne Victoire Boivin; Rosalyn Yalow.

CALVIN FULLER

American physical chemist

Fuller was one of the inventors of the first efficient silicon solar cell. Solar cells have provided a renewable resource for electricity and have made space exploration possible.

Born: May 25, 1902; Chicago, Illinois
Died: October 28, 1994; Vero Beach, Florida
Also known as: Calvin Souther Fuller (full name)
Primary fields: Chemistry; electronics and electrical engineering; physics
Primary invention: Silicon solar cells

EARLY LIFE

Calvin Souther Fuller was born to Bessie and Julius Quincy Fuller in Chicago, Illinois. After graduating high school, Fuller attended the University of Chicago, where he received a B.S. in physical chemistry. He continued his studies at the University of Chicago and in 1929 was awarded a Ph.D. in physical chemistry.

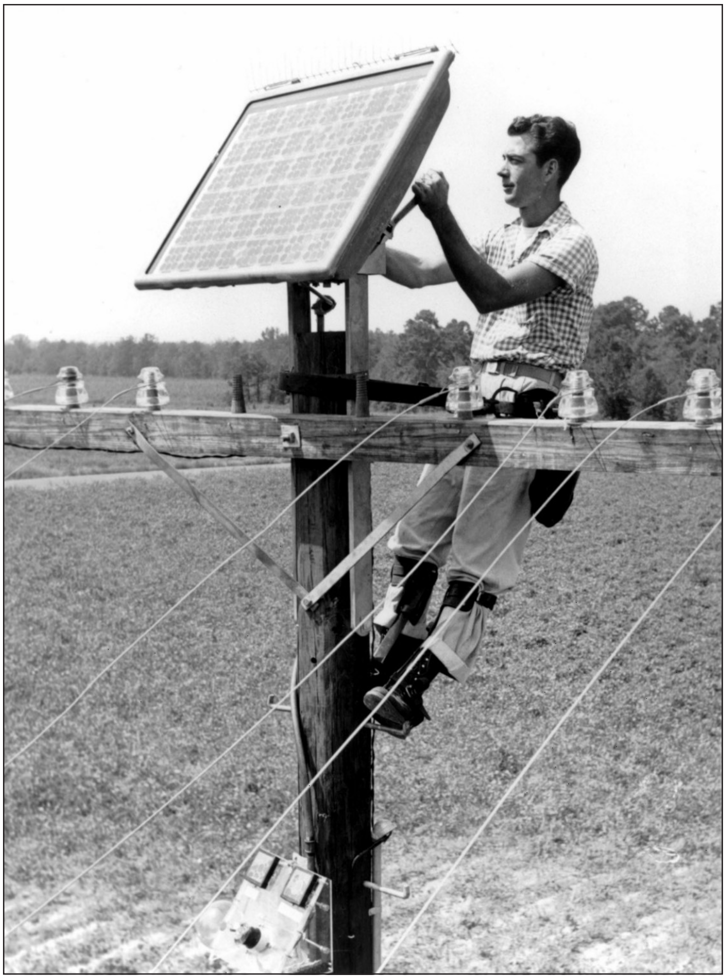
Fuller began working for Bell Laboratories the year after his graduation. His first projects were developing insulating materials and researching polymers. During World War II, he served as the head of synthetic rubber research for the U.S. government, investigating new products that could replace real rubber, of which there was a shortage during the war. In 1948, he began developing semiconductors for Bell Laboratories. He and his wife, Willmine, had three children: Robert, Stephen, and John.

LIFE'S WORK

In 1952, at Bell Labs, Daryl Chapin was given the task of solving a problem with the batteries in the Bell telephone system. The batteries worked well in temperate climates, but in hot, wet tropical climates they quickly degraded. Chapin at the time was investigating alternative forms of energy such as wind machines. He suggested that solar cells might be a solution to the battery problem.

The first solar cell was designed by Charles Fritts in 1883. It was made of selenium and gold but was only about 1 percent efficient. By 1952, selenium solar cells had been modestly improved, but they produced a paltry 5 watts per square meter, which equated to harnessing less than one-half of one percent of the available energy in the sunlight. Chapin wanted to achieve capturing at least 6 percent of the solar energy with a cell.

During this time, in March, 1953, Fuller was collaborating with Gerald Pearson on semiconductors, experimenting with silicon to make the semiconductors. In 1946, Bell Labs employee Russell Ohl had developed a method to reduce the impurities in silicon so that it could



A technician works on the Bell Solar Battery for a test in 1955 in Americus, Georgia. On April 25, 1954, Calvin Fuller, Daryl Chapin, and Gerald Pearson publicly demonstrated the first practical silicon-based solar cell, which was later used in the Bell telephone system. (AP/Wide World Photos)

Solar Cells

Solar cells are made from silicon, which, in the case of the cell developed by Calvin Fuller, Daryl Chapin, and Gerald Pearson, is doped with arsenic. Silicon is an atom that has four outer electrons that bind with four other silicon atoms to make a lattice in which each silicon atom shares an electron with another atom. Each silicon atom in the lattice has eight electrons surrounding it: four of its own and the other four from the surrounding four silicon atoms. In this form, the lattice has a neutral charge. However, arsenic has five outer electrons, so when an arsenic atom replaces a silicon atom in the lattice, the arsenic has four bonded electrons and one extra, unbonded electron. The extra electron gives the semiconductor a negative charge, making it an N-type semiconductor.

When the semiconductor is bathed in boron, the opposite situation occurs. Boron has only three electrons in its outer shell, and when it enters the silicon lattice, it creates a "hole," because one bond between the boron and silicon atom has only half of a bond. Thus, a boron-doped semiconductor is a P-type semiconductor because it has a positive charge. When a solar cell is constructed, an N-type chemical is added to one side of a P-type strip, or a P-type chemical onto an N-type strip.

When a section of P-type silicon is next to an N-type silicon, it forms a PN junction. When the silicon is exposed to sunlight, electrons are freed from the N-area to flow through the silicon, producing electricity. The freed electrons leave positively charged holes that flow in the opposite direction of the electrons. If 100 percent of the electrons that are freed flowed out of the cell into the electrical wires, then the cell would have 100 percent efficiency, but many of the electrons go back into the lattice to fill in the holes in the P-area and thus do not contribute to electricity generation.

function as a semiconductor. Ohl realized that the impurities in the silicon created resistance and thwarted electron flow. Fuller had perfected a chemical process to remove even more impurities from the silicon so that it would be a better electrical conductor. He also added a small amount of gallium to give the silicon a positive charge. After bathing the silicon in lithium, Pearson shone light on the piece and recorded the amount of electricity it produced. The silicon made a much-improved solar cell compared to the selenium solar cell. Pearson and Chapin were good friends, and Pearson shared the information about the superiority of the silicon cell with him.

Pearson's cell worked about five times better than Chapin's selenium cell, but Chapin found it very difficult to make electrical connections to the silicon to collect the electricity it was producing. He could not solder wires directly to the silicon, and attempts to electroplate various metals to the silicon failed. Chapin approached Fuller for help in fixing his PN junction (the point of contact between positively charged and negatively charged semiconductors), as Fuller had successfully worked with PN junctions a few years earlier when he was developing transistors. Fuller substituted the lithium with phosphorous, which doubled the output of the cell, but unfortunately it was still shy of Chapin's 6-percent goal.

In the meantime, Radio Corporation of America (RCA), Bell Labs' main rival, unveiled to the public its Atomic Battery, which was powered by photons from a nuclear-waste product, strontium 90. RCA's goal in using the strontium 90 was to demonstrate that nuclear waste could be reused productively. Unfortunately, strontium 90 has since been categorized as a highly dangerous component of nuclear waste and an unsafe choice for inclusion in batteries. Interestingly, the Atomic Battery could also be powered by solar photons, so when the RCA scientists performed their first public demonstration, they had to shield the battery from the Sun so that it would only be powered by the strontium 90.

The success of the Atomic Battery put pressure on Bell Labs to accelerate its solar cell work. Fuller went back to the drawing board and developed a completely new process for making silicon into a solar cell. Instead of using the positively charged gallium, he mixed arsenic with the silicon to give the silicon a negative charge, and then he cut the silicon into thin strips. When coated with a layer of boron, the cell had a PN junction very close to the surface of the cell. This allowed for good electrical contacts for transporting the electricity off the cell. One of these designs finally achieved Chapin's goal of 6-percent efficiency.

The Bell Solar Battery was first presented to the public on April 25, 1954. Bell Labs held a press conference to demonstrate the solar battery by having it power a radio transmitter. Bell Labs claimed that the battery could produce 50 watts of electricity per square yard of cell. By 1955, Bell was using the cell in its telephone carrier system; in 1958, the cell was used to power the U.S. Vanguard 1 satellite, the first satellite to use solar energy.

Bell Labs owned the patents Fuller received while he was working for the company, so Fuller never became wealthy as a result of his inventions. This did not bother him, however, as he received great personal satisfaction from his scientific achievements. Altogether, Fuller and Bell Laboratories were granted thirty-three patents for his semiconductor and solar cell developments.

Fuller retired to Vero Beach, Florida. From there, he made many trips across the United States with his wife in a Silver Stream camper. He died in Vero Beach in 1994. On June 22, 2006, Fuller was inducted into the New Jersey Inventors Hall of Fame for development of the semiconductor photovoltaic solar cell. Along with Daryl Chapin and Gerald Pearson, he was inducted into the National Inventors Hall of Fame on May 2, 2008.

IMPACT

The invention of the solar cell and its applications have had far-reaching consequences in many areas. The solar cell gave the U.S. space program a source of energy to use for its satellites, spacecraft, space station, and remote moon and planetary landers. Without solar power generators, satellites could not continue to function in orbit for years, the rovers *Spirit* and *Opportunity* could not have explored Mars, and the International Space Station project would never have gotten off the ground. In the early twenty-first century, the international market for solar-generated electricity sometimes grew by more than 25 percent per year. Today's commercially produced solar cells have a life span of at least twenty years before they begin to lose efficiency.

Solar cells can be used to generate electricity in locations where there is no other power source. They light remote road signs and power solar cars. Solar cell arrays are used to generate electricity for commercial factories, warehouses, and stores as well as private homes. They can be made large enough to provide electricity for towns or small enough to power a handheld calculator. New flexible solar cell materials are being used to make military tents so soldiers can have air conditioning and power for their entertainment devices; the materials are also used to make cases for electronic equipment such as cell phones, laptops, and radios so the devices can be recharged without having to plug them into a standard electrical socket. The power produced can be used directly, stored in a battery until needed, or sent into the commercial power grid. The ability to store the generated electricity is very important, as solar panels must be exposed to sunlight to generate electricity, so they do not work at night or on cloudy days.

When the function of the solar cell is reversed, electricity can be converted into light. This process allows for fiber-optic lines to carry data, a technology that transmits telephone calls, television signals, and information throughout the Internet.

—*Polly D. Steenhagen*

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See also: John Bardeen; Jack St. Clair Kilby; Robert Norton Noyce; Gerald Pearson; William Shockley; Maria Telkes.

R. Buckminster Fuller

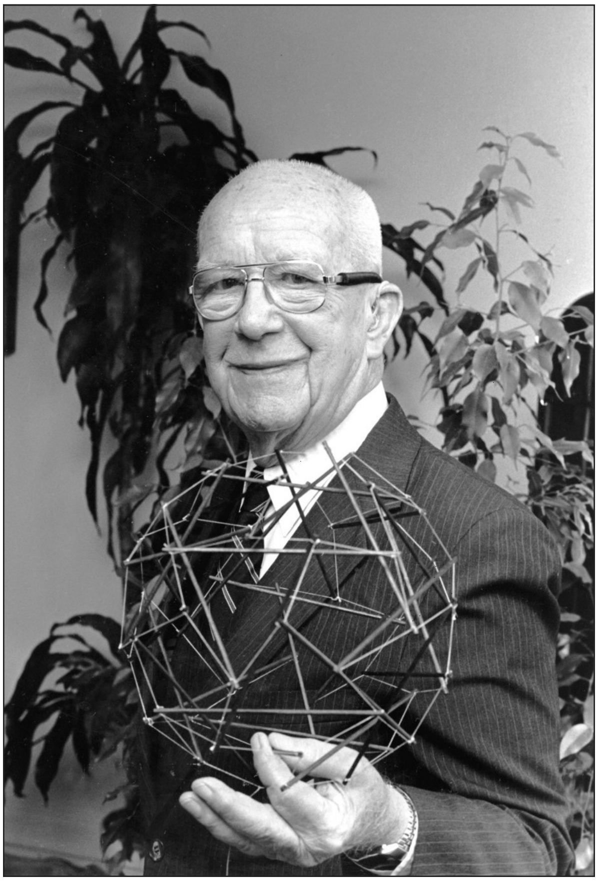
American designer, architect, and philosopher

Fuller is best known for his geodesic dome, a structure now familiar around the world. A prolific, autodidact philosopher, Fuller proposed design principles to benefit humankind.

Born: July 12, 1895; Milton, Massachusetts
Died: July 1, 1983; Los Angeles, California
Also known as: Richard Buckminster Fuller, Jr. (full name); Bucky Fuller
Primary fields: Architecture; civil engineering
Primary inventions: Geodesic dome; Dymaxion products

Early Life

Richard Buckminster Fuller, Jr., was born to Richard Buckminster Fuller and Caroline Wolcott Andrews in 1895. He spent much of his early years on Bear Island in Penobscot Bay, Maine. He liked it so well there that in his later years he set aside the month of August for visits to the island. He was born with extreme farsightedness, and it was not until he was four years old that the condition was recognized and eyeglasses prescribed. He compensated for his impaired vision by relying on his other senses.



R. Buckminster Fuller, inventor of the geodesic dome, holds an object that demonstrates the architectural principle of tensegrity. (AP/Wide World Photos)

Sailing was an important activity in Fuller's youth, and he showed his mechanical inventiveness at an early age when he built an umbrellalike, collapsible cone to propel his small boat forward. His mechanical oar was patterned after the motion of jellyfish. Observing how nature works would continue to play an essential role in his problem solving.

"Bucky," as he was called then, was sent to Milton Academy, a well-known New England preparatory school. It was set up as a boarding school, but because of his father's ailing health and financial stresses, he attended as a day student. He quickly showed his propensity for nonconformity, and his constant questions and curiosity were seen as a challenge to authority.

His troubles with formal education did not stop with Milton Academy. His family had a long and glowing history of attendance at Harvard, and in 1913 he entered the freshman class to take his place in that tradition. Unfortunately, he was unable to uphold the good reputation and was expelled twice from the university, concluding his attendance in higher education in 1915 to move to New York City, where he took a job in the meatpacking firm of Armour and Company. Although he never went back to school in a formal setting, he was eventually awarded many honorary doctorates for his intellectual work.

Life's Work

In 1917, Fuller married Anne Hewlett. Their first child, Alexandra, was born December 12, 1918, but contracted infantile paralysis and spinal meningitis and died in 1922. At that time, he lost his position as national account sales manager with the Kelley-Springfield Truck Company and began his career as an independent thinker. His first venture was founding the Stockade Corporation, manufacturing buildings using a technology invented by his father-in-law. By 1927, the business had failed to make a profit, and Fuller was fired.

Fuller was penniless, drinking heavily, and reportedly on the verge of suicide, but he overcame his depression with a personal mission: to explore what he could do to benefit humankind. That year, he founded the 4D Company to research and develop his ideas for the Dymaxion house and car, and he had his second child, Allegra. (“Dymaxion” is derived from the words “dynamic,” “maximum,” and “ion.”) The Dymaxion house was designed to be mass-produced and air-deliverable. Fuller also designed a Dymaxion bathroom, a single-unit enclosure that included a washbasin, tub, shower, and toilet. It was the predecessor to the modern fiberglass tub and shower units. In 1928, he published his first book, *4D Timelock*.

The Dymaxion car made its first public showing on July 12, 1933. Originally conceived as a jet-propelled vehicle capable of land, sea, and air travel, the final version was a V-8 gasoline-powered, nineteen-foot-long car. It featured many innovative ideas, such as front-wheel drive, three wheels for increased mobility, and a capacity for eleven passengers. The sausage-looking car, with its astounding maneuverability, was a hit at the 1934 Chicago World’s Fair. Unfortunately, the Depression and an accident caused the Dymaxion car to be stillborn in its formative phase.

In 1946, Fuller patented an idea for a world map that did not have the distortions common on other flat maps. A globe, unlike most flat maps, accurately represents the proportions of areas regardless of their position on the globe. However, globes cannot be laid flat and transported from place to place. With the invention of the Dymaxion map, the distortions inherent in flat maps all but disappeared. This was done by dividing the globe into a spherical icosahedron (a polyhedron with twenty triangular faces) and then flattening out each triangle. While the distortions disappeared, the map was difficult to read and thus did not replace conventional maps.

During the 1960’s, Fuller developed a “world peace game,” later called World Game, for policy makers and voting citizens to provide perspective on the looming problems associated with overpopulation and distribution of resources. Fuller intended his game to be a serious tool for analysis. Armed with accurate statistics, the participant evaluates energy, food, and ecological requirements to achieve positive effects for all humankind without cost to any subgroup. The game was seen by many as utopian and at odds with capitalism and free market economies.

Probably the most comprehensive collection of written evidence of a man’s life is Fuller’s “Chronofiles,” essentially an enormous scrapbook (estimated at 270 feet worth of paper) that covers his life between 1915 and 1983. In the early twenty-first century, the files were still being indexed and categorized to make locating informa-

THE GEODESIC DOME

Of R. Buckminster Fuller’s twenty-nine patented inventions, the one that saw the most widespread use was his geodesic dome, which he designed in 1947 and patented in 1954. Like many inventions, the entire idea was not original to Fuller, as Walther Bauersfeld had built a similar structure in 1922 while working for the Carl Zeiss optical company to house a planetarium.

Fuller refined and popularized the idea to the extent that he is known today as the “father of the geodesic dome.” Prototypes were constructed by Fuller and his students at Black Mountain College in North Carolina during the summer sessions he taught there in the late 1940’s. The first practical application of his concept was completed in 1953 for the Ford Motor Company at its River Rouge headquarters. The successes there led to contracts in 1954 for family-sized geodesic domes for the Marine Corps that were delivered by helicopter and featured on the front page of *The New York Times*.

Over time, as the geodesic dome gained acceptance, the design began to appear all over the world. A variation of the design was used by the U.S. military to protect its radar units in the Arctic in 1955. A 100-foot-diameter dome was flown to Kabul, Afghanistan, for the International Trade Fair in 1956, and Fuller designed and supervised the construction of the 384-foot-diameter geodesic dome for the Union Tank Car Company in 1957. It was the largest clear-span structural enclosure in the world at that time. By 1961, more than one hundred companies were licensed to build the domes and more than two thousand were produced in that year. Most of the domes were delivered by air to forty countries around the world, as well as the north and south polar regions.

Fuller’s interest in the geodesic dome stemmed in part from his lifelong fascination with nature’s coordinate system. The structural beauty of the dome is its reliance on “tensegrity” (tensional integrity), a term coined by Fuller for artist Kenneth Snelson and his 18-meter-high Needle Tower (1968). Tensegrity describes a system that is in balance between tension and compression. Fuller’s domes were composed of sections of spheres interconnected in a complex way so as to be both strong and light. Although the domes have some drawbacks for residential structures, they are unsurpassed for their strength-per-weight ratio, and as a sphere encloses the greatest volume with the least surface area, they are efficient for heating and cooling.

tion easier. Everything from lecture notes to letters to friends are included.

Fuller was in great demand as a speaker all over the world until the last days of his life. In 1983, he died of a heart attack while visiting his comatose wife, Anne, at Good Samaritan Hospital in Los Angeles. He had been evaluated in good health three weeks earlier. Anne never came out of her coma and died thirty-six hours later.

IMPACT

Fuller was one of the early futurist and global thinkers, as well as a teacher, inventor, and engineer. He had a long and active life, lecturing and continually traveling into his eighties. During his career, he earned twenty-nine patents, wrote twenty-nine books, and was awarded forty-seven honorary degrees. He was full of ideas that ranged from interesting to incomprehensible. Several of these ideas made it to production, including his Dymaxion house, car, and map.

Twenty-five years after his death, Fuller's ideas continued to germinate and resonate in a world challenged with managing finite resources. In 2008, the first annual Buckminster Fuller Prize of $100,000 was awarded to Dr. John Todd for his Comprehensive Design for a Carbon Neutral World. The prize was given by the Buckminster Fuller Institute, founded in 1983 to honor and continue the pioneering work on global issues begun by its namesake.

Although Fuller's inventions continue to interest people, his primary impact may be in the continuance of his ideas regarding the future of the human race on Earth. Two rich sources for mining of the mind of Fuller are his World Game and Chronofiles.

—*Tom A. Hull*

FURTHER READING

Fuller, R. Buckminster. *Critical Path*. New York: St. Martin's Press, 1981. Fuller's last major book, *Critical Path* was published two years before his death. It encompasses in conversational language the breadth of his ideas about the past and future of life on Earth. Devoid of much of the heavy mathematics and technical terms of some of his earlier work, this is a good choice for general readers.

_______. *Operating Manual for Spaceship Earth*. New York: E. P. Hutton, 1963. Written with the idea that Earth is a giant spaceship with finite resources that cannot be resupplied, this book goes a long way toward explaining why Fuller was in such great demand as a speaker until the last days of his life. Includes many of his important ideas on how humans can survive as a cooperative society.

_______. *Synergetics: Explorations in the Geometry of Thinking*. New York: Macmillan, 1975. Reported by some to be "nonsense," this is his seminal work in which he attempts to explain nature's mathematical code. If the reader can plow through the convoluted style, the reward is observing a masterful thinker at work.

Sieden, Lloyd Steven. *Buckminster Fuller's Universe*. New York: Plenum Press, 1989. This biography includes personal information about Fuller but concentrates on how his ideas have influenced the world. Sieden has written this book "to break the code and translate his most significant thoughts into accessible language."

See also: Giovanni Branca; Walt Disney; Robert Hooke; Thomas Jefferson; Gerardus Mercator; John Augustus Roebling; Frank Lloyd Wright.

ROBERT FULTON

American civil engineer

Fulton's Hudson River steamboat was the first fully successful application of steam power to navigation. The side paddle-wheel boats he created were particularly suited to the extensive river system of the continental United States.

Born: November 14, 1765; Little Britain Township, Lancaster County, Pennsylvania
Died: February 24, 1815; New York, New York
Also known as: Robert Fulton, Jr. (full name)
Primary fields: Civil engineering; naval engineering
Primary invention: Paddle-wheel steamboat

EARLY LIFE

Robert Fulton's parents were Protestant Irish immigrants. Unable to make a living at farming, they moved to Lancaster County, Pennsylvania, in 1772, when Robert was six years old. His father, Robert, died two years later. His mother, Mary, taught him to read and write and enrolled him in a Quaker school when he was eight. The child showed little interest in academic matters, preferring to spend time watching mechanics at work and drawing the world around him. Later, when he was apprenticed to a Philadelphia jeweler, his master made use of Fulton's artistic abilities, having him paint miniature portraits on ivory that could be used in lockets and rings.

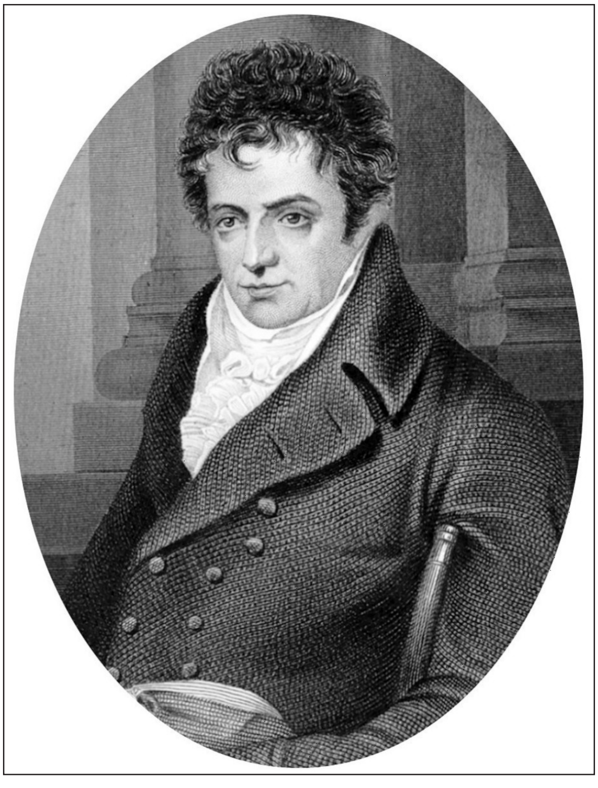
When he turned twenty-one in 1787, Philadelphia merchants, impressed with his artistic ability, financed a trip to England, where he could study with Benjamin West, the American painter whose portraits and historical paintings were prized by British royalty and aristocracy. Fulton was modestly successful as a portrait painter. Two of his portraits were accepted for the Royal Academy exhibition of 1791, and four in 1793; a few aristocrats commissioned portraits. However, his meager earnings convinced him to turn to his mechanical and engineering interests.

In 1794, Fulton focused on canals. His *A Treatise on the Improvement of Canal Navigation* (1796) advocated building a network of small canals across the countryside, using inclined planes rather than locks to raise and lower barges. Fulton's ideas found little favor. In 1797, he traveled to France to push a proposal for a submarine that would plant explosives against British ships. Fulton built a prototype that successfully functioned underwater, but his mines failed to damage any ships. Offered later to the British and to the United States, his mines proved impractical each time.

LIFE'S WORK

While in Paris in 1802, Fulton met Robert R. Livingston, American minister to France, who had used his political power to obtain a twenty-year monopoly on steamboat operation in the state of New York. The monopoly grant would expire unless Livingston produced a steam-powered ship able to go upriver against the current at four miles per hour. Fulton formed a partnership with Livingston to design and build such a ship and began to spend most of his time on steamboat design, while continuing to advocate his naval warfare innovations.

Fulton used two French studies of underwater resistance of boats to calculate water pressure to be expected from various designs of hull shapes and of paddle wheels or oars. He had model boats built with which to experiment and test out ideas on their structure. There had been many futile attempts to build a successful steamboat; Fulton was undoubtedly aware of several. He settled on a long narrow hull (seventy-five feet by eight feet) with very large side paddle wheels, twelve feet in diameter



Robert Fulton. (Library of Congress)

managed to get the Boulton and Watt engine he desired. Spurred by Fulton, the boat builders had a ship ready for trials in early August. The hull was 146 feet long and 12 feet wide; to lessen resistance, it had a flat bottom and straight sides, tapered at the bow. A test run on August 7 convinced him that the Boulton and Watt engine was sufficiently powerful to permit increasing the size of the side paddle wheels to fifteen feet in diameter.

On August 17, 1807, Fulton's steamboat left for Albany, stopping for the night at Livingston's Hudson River estate, Clermont (whose name was later applied to the ship), before proceeding to Albany in an incident-free voyage. The 150-mile trip took thirty-two hours at an average speed of 4.7 miles per hour against the flow of the Hudson River, an achievement amazing New Yorkers accustomed to sailing sloops taking four days to cover the same route, and stagecoaches needing sixty hours to connect the two cities.

Fulton began commercial trips in September after building an engine house and providing cabins with berths for passengers. The ship made three round-trips between New York City and Albany every two weeks, despite occasional equipment failures and problems caused by sloops "accidentally" crashing into the paddle wheels of the new, resented rival. Over the winter, he placed guards over the wheels, widened and lengthened the boat, and made the passenger cabins more luxurious. Fulton's last and most powerful ship reduced the time to Albany to just over twenty-one hours in 1816. As voyages continued with no major accidents, passengers began to flock to the ship, which became very profitable carrying people and light cargo. In less than eight years, Fulton put sixteen steamboats into operation on the Hudson and other American rivers. Double-ended steam ferries crossed to Brooklyn and New Jersey, replacing boats powered by horses on treadmills. The street connecting his ferry terminals on the Hudson and East rivers was rebuilt and renamed Fulton Street in 1816.

with ten arms, powered by an eight-horsepower French-built engine. Placing the heavy steam engine on a beam that distributed its weight across the hull prevented the pounding of the engine from damaging the ship. The boat's top speed was only three miles per hour. Fulton expected greater speed from the twenty-four horsepower, single-cylinder condensing steam engine built by Britain's Boulton and Watt, the world's premier steam engine manufacturer, that he planned to use in his Hudson River boat.

Fulton arrived in New York in December, 1806, and started construction of an improved version of the boat he had tested in Paris. Despite British attempts to prevent export of the nation's superior technology, Fulton had

PADDLE-WHEEL STEAMERS

Robert Fulton never claimed to have invented the idea of a steamboat. It is doubtful anyone could successfully make that claim. Once Thomas Newcomen and James Watt had proved the economic feasibility of stationary steam engines to remove water from mines, many mechanically minded Europeans and Americans speculated about how such engines might be used to move ships, wagons, and railcars. All three goals would be achieved in the nineteenth century.

Fulton insisted an idea was not an invention; demonstration of its workability was decisive. He believed his French experiments had revealed the fundamental relationships between engine power, propulsive mechanism, and hull design that changed steamboats from ideas to commercial reality. Fulton claimed that his major contribution in constructing the first commercially successful steamboat were his designs for the paddle wheels on each side of his boat.

There had already been much discussion about how to use steam power to produce propulsion. Benjamin Franklin thought paddles would not generate enough power and suggested propelling a jet of water out the back of the boat to move it forward, but attempts to build such ships were unsuccessful. One inventor built a ship with oars attached to horizontal bars on each side of his vessel, looking like an ancient galley with steam power replacing galley slaves, also without success. Another tried screw propellers with blades similar to those on windmills at the rear of his ship. At one point, Fulton considered stern paddles that moved side to side like a fish tail. Others tried versions of paddle wheels at the rear or the sides of vessels, but they lacked Fulton's carefully tested design.

On oceangoing ships, paddle wheels were problematic; storm waves could raise them out of the water, making steering difficult. On the broad, relatively smooth American rivers, however, the paddle wheel was an effective impeller in the early nineteenth century. Only after the heyday of the Mississippi steamboat was over did efficiently designed screw propellers become the mechanism of choice. Until then, Fulton's side paddle-wheel design dominated early American steamboats as they stimulated the economic development of the country.

In 1811, Livingston and Fulton had a boat constructed to Fulton's design in Pittsburgh, planning to send it south to New Orleans to validate their claim to a steamboat monopoly on rivers of the Louisiana Territory. It was a most eventful journey. As the *New Orleans* approached the Mississippi River on December 16, the first of three magnitude-8 earthquakes and some 1,500 aftershocks erupted, making the New Madrid quake the most powerful to hit North America in recorded history. The quake radically altered the landscape, changing the course of the Mississippi, leveling hills, and scattering debris over the river. Despite the dangers, the boat continued south and arrived at New Orleans on January 10, 1812, surprising many who had not believed it could complete so long a voyage, even without an earthquake. The boat provided regular service between New Orleans and Natchez, Mississippi; in 1815, a newer ship extended the route to Louisville on the Ohio River. More powerful engines and reduced draft would be needed before steamboats fully conquered the Mississippi and its tributaries.

In 1808, Fulton married Livingston's niece Harriet; they had a son and three daughters. Fulton spent most of his remaining years and much of his fortune engaged in litigation with rival steamboat builders who challenged his lucrative monopolies. In the winter of 1815, returning from Trenton, New Jersey, after testifying in a law case, Fulton took a chill, came down with pneumonia, and died.

IMPACT

Fulton's steamboat revolutionized river commerce in the United States and provided an enormous spur to the economic development of the nation. His design was particularly well adapted to America's broad and relatively placid rivers. Paddle wheels were unusable on canals, where the disturbance they created threatened erosion of earthen walls. However, first on heavily traveled routes up the Hudson River and across Long Island Sound, then on rivers along the Atlantic coast, steam-powered boats reduced travel time, cut costs, and increased reliability for passengers and cargo alike.

The invention had even greater impact in the West, as steamboats opened the extensive Mississippi-Ohio-Missouri river system to profitable commerce. Previously, goods from the Ohio country could be rafted down to New Orleans and the raft broken up and sold for lumber, but the return voyage was nearly impossible, and a long slog overland difficult for crews walking back home, much less carrying cargo. Two innovations adapted steamboats to conquer the entire Mississippi River system. Reducing the draft of the boats to nine to twelve inches permitted moving up the Missouri River into Montana and navigating the Red River into the Southwest. High-pressure (Oliver) Evans-type engines were lighter in weight and produced four times as much horsepower as Fulton's Boulton and Watt engine. Fulton had avoided high-pressure engines, thinking they were too likely to explode and start fires—a problem that plagued Mississippi steamboats competing to provide the fastest service. No passenger or crew member was hurt or killed while on any of Fulton's boats.

Moving cargo by water was always cheaper than hauling goods by land. Steamboats held off the challenge of railroads until after the Civil War, boasting ever more luxurious passenger accommodations and setting records racing against each other on the Mississippi. The enormous expansion of farming and industrial development of the central United States was made possible by Fulton's invention.

—Milton Berman

FURTHER READING

Philip, Cynthia. *Robert Fulton: A Biography*. New York: Franklin Watts, 1985. A detailed biography of Fulton based on careful source research and basically favorable to Fulton. Heavily used by all later writers.

Sale, Kirkpatrick. *The Fire of His Genius: Robert Fulton and the American Dream*. New York: Free Press, 2001. Sale believes that Fulton exaggerated his claims to originality but credits him with being the first person to make steamboats a commercial reality.

Sutcliffe, Andrea. *Steam: The Untold Story of America's First Great Invention*. New York: Palgrave Macmillan, 2004. Mostly concerned with the battle between John Fitch and James Rumsey to claim priority for their steamboats. Draws heavily on Philip and Sale and treats Fulton as a money-loving adventurer.

See also: David Bushnell; Oliver Evans; John Fitch; Thomas Newcomen; John Stevens; James Watt.

DENNIS GABOR

Hungarian British electrical engineer

Known as the "father of holography," Gabor was awarded more than one hundred patents for inventions dealing with communication theory, physical optics, plasma theory, magnetron theory, and television. Gabor's invention of holography, a lensless method for producing three-dimensional images of objects, has myriad practical applications.

Born: June 5, 1900; Budapest, Hungary
Died: February 8, 1979; London, England
Also known as: Gábor Dénes (birth name)
Primary fields: Optics; physics
Primary invention: Holography

EARLY LIFE

Dennis Gabor (GAH-bohr) was the oldest of three sons born to Bertalan, director of the Hungarian General Coal Mines, and Adrienne Gabor, a former actress. In his youth, Gabor became very interested in scientific investigations and conducted several experiments with his brother George that involved the use of X rays and radioactivity in a home laboratory that they had built together. He loved to explore the inner workings of any thing around him. By age eleven, Gabor had received his first patent for a carousel that employed tethered airplanes.

Dennis Gabor won the 1971 Nobel Prize in Physics for his invention of holography. (Getty Images)

After serving in the Austro-Hungarian army during World War I, Gabor began the pursuit of a degree in mechanical engineering at Budapest Technical University in 1918. Upon a second request that he serve in the army, in 1920, he left Hungary and traveled to Germany, where he entered the Technical University of Berlin in 1921. While there, he earned a degree in electrical engineering (1924) and his doctorate in the same field (1927). His doctoral dissertation focused on the development of one of the first high-speed cathode-ray oscilloscopes and the invention of the first iron-covered magnetic electron lenses.

During his school years in Berlin, Gabor often visited the University of Berlin to increase his knowledge about physics. He attended lectures and seminars presented by Max Planck, Albert Einstein, Max von Laue, and other prominent physicists of the time. Upon completion of his doctorate, Gabor was employed as a research engineer by Siemens and Halske in Berlin. While working there, he made one of his first successful inventions, a high-pressure quartz-mercury lamp that used superheated vapor and a molybdenum tape seal. Upon Adolf Hitler's rise to power in 1933, Gabor moved to England, where he worked for British Thomson-Houston (BTH) in Rugby, Warwickshire, for the next fifteen years. In 1936, he married Marjorie Louise Butler, the daughter of Joseph and Louise Butler. The couple had no children.

LIFE'S WORK

Due to Gabor's expertise with gas discharge tube technology, he was assigned to work in the BTH Research Laboratory in 1933. His major research work focused on improving the resolution of the electron microscope. In 1946, he published some of the results of his research in *The Electron Microscope: Its Development, Present Performance, and Future Possibilities*.

By 1947, Gabor thought that he had finally solved the resolution problem. He decided that the unclear picture obtained from an electron microscope contained the complete information about the object under investigation. His idea was to clarify the distorted electron image using optical methods to recover all the information about the object. Gabor suggested splitting the electron beam into two beams, reflecting one of the beams off the object of interest and the other off a mirror. When the resultant beams were recombined on a piece of photographic film, an interference pattern would result because the two beams traveled different path lengths.

Gabor proved mathematically that when light was shone back through the unclear filmed image, a three-dimensional picture of the object would be reconstructed. He termed the process "wavefront reconstruction," and coined the term "hologram," meaning "whole message," as the name for the unclear image captured on film. Using a mercury lamp and directing its light through a pinhole, Gabor produced some inexact holograms, which proved the feasibility of his method. He published his initial results about holography in *Nature* in 1948, followed by papers on optical imaging and holography in *Proceedings of the Royal Society* in 1949 and in *Proceedings of the Physical Society* in 1951.

On January 1, 1949, Gabor left BTH and began teaching electronics and applied physics at the Imperial College of Science and Technology at the University of London. During his eighteen years there, with the assistance of several graduate students, he developed a number of inventions that included a high-frequency Wilson cloud chamber to identify elementary particles; a holographic microscope; an analog computer; an electron-velocity spectroscope; a new type of thermionic converter; a flat, thin color television tube; and a stereoscopic cinematography system that he had initially worked on at BTH. Gabor and some postdoctoral students clarified the Langmuir paradox by explaining why intense electron interactions occur in plasmas.

In addition to his inventions, Gabor also conducted research on how humans communicate and hear, which led to the theory of granular synthesis. In 1956, he was nominated as a fellow of the Royal Society. Two years later, he was promoted to a professor of applied physics at the Imperial College, where he remained until his retirement in 1967. Gabor was honored with the Thomas Young Medal of the Physical Society of London as well as the Cristoforo Colombo Prize of the International Institute for Communications in Genoa, Italy, in 1967. One year later, he was awarded both the Albert Michelson Medal of the Franklin Institute of Philadelphia and the Rumford Medal of the Royal Society.

HOLOGRAPHY

While working on improving the resolving power of the electron microscope in 1947, Dennis Gabor asked himself what would happen if the fuzzy image captured by the device were clarified optically in order to obtain all the information about the imaged object. Instead of just the beam of light generated by a stream of electrons, he expanded the concept to include electromagnetic radiation (light) in general. His idea involved splitting the beam of light from the source into two beams, one directed upon the object to be analyzed and the other reflected off a nearby mirror. Both beams of light would initially have the same wavelength (monochromatic) and be in phase (coherent). Upon reflection, the beam from the mirror would remain unchanged, while the beam from the object would contain all the three-dimensional impressions and irregularities imposed on it by the object. When the reflected beams were collected onto a piece of photographic film, they would be generally incoherent and interfere with each other. As the waves cross paths and interfere, they produce standing wave patterns that can be photographed because the patterns are standing still in space. When these waves patterns were captured on film, Gabor reasoned that the resulting interference pattern should contain all the information about the object. He coined the term "hologram" (a combination of Greek words that means the "whole message," or the "complete picture") to represent the unclear, photographed interference pattern.

Using physical reasoning and a mathematical derivation, Gabor determined that if coherent light were shone back through the film to illuminate the interference pattern, the original wavefront would be reconstructed, and the light would transform this unclear interference pattern into a three-dimensional image of the original object. He proceeded to use a mercury lamp that he shined through a pinhole to produce the first, though rather diffuse, holograms. Further developments in holography were stymied until the invention of the laser, a true monochromatic, coherent light source, by Theodore Maiman in 1960. Emmett Leith and Juris Upatnieks, graduate students at the University of Michigan, read Gabor's papers on holography and produced the first clear, realistic holograms in 1962. Gabor was one of the first people to pose for a holographic portrait. Because of Gabor's inventive genius, holography has made a positive, practical impact on a wide variety of applications that include high-resolution imaging, information storage and processing, and interactive three-dimensional displays.

During his retirement years, Gabor continued to work as a senior research fellow with the Imperial College and as a staff scientist for CBS Laboratories in Stamford, Connecticut, on problems associated with communication. He also spent a lot of time vacationing at his private villa near Rome, Italy, where he enjoyed sunbathing, reading, writing, and singing. In 1970, he was honored as a Commander of the Order of the British Empire and also received the Medal of Honor of the Institute of Electrical and Electronics Engineers. One year later, he was awarded the Holweck Prize of the French Physical Society. That same year, he received the Nobel Prize in Physics for his invention of holography.

During the 1970's, Gabor became more and more concerned with the function of science and technology in society and the future of an industrial civilization. He strongly believed that inventors should consider social inventions and advancements as their top priority. Some of his insights into the social implications of technological advancements led him to publish *Innovations: Scientific, Technological, and Social* (1970), *The Mature Society: A View of the Future* (1972), and *Proper Priorities of Science and Technology (*1972). Gabor died in London on February 8, 1979.

IMPACT

Gabor's inventive philosophy is encapsulated in his famous statement, "You can't predict the future, but you can invent it." He is a prime example of a scientist and inventor who relentlessly and methodically brought his ideas to fruition even when the final practical outcome was something quite different from his initial pursuit. He had his first encounter with serendipity in the late 1920's, when, in his attempt to invent a cadmium lamp, he instead invented the mercury lamp, which was used in thousands of street lamps. His second encounter with serendipity came about twenty years later, when, in trying to make improvements to the electron microscope in order to resolve atomic lattices and see individual atoms, he invented the process of holography.

Since there were no coherent, monochromatic light sources available when Gabor invented holography, his initial demonstrations were not very impressive, but they verified that the process worked. The full impact of his inventive genius was not realized until the early 1960's after the laser was invented. Since the laser provided an intense, coherent, monochromatic light source, clear three-dimensional images using Gabor's holographic method were being produced by 1962. Since that time, holograms have been used increasingly in myriad ways that include applications in medicine, cartography, computer information storage, and advertising, and on credit cards to prevent counterfeiting.

During his career, Gabor was awarded more than one hundred patents and published numerous papers and books. In his honor, the International Society for Optical Engineering presents the annual Dennis Gabor Award to recognize significant accomplishments in diffractive wavefront technology, particularly holography, while the Hungarian Academy of Sciences presents the International Dennis Gabor Award each year to young scientists who make important contributions in applied physics and technology.

—*Alvin K. Benson*

FURTHER READING

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Heckman, Philip. *The Magic of Holography*. New York: Atheneum, 1986. Heckman presents a history of the developments in holography from important early discoveries in the field of optics to the first hologram produced by Gabor. Potential future applications of holography and their practical implications are explored.

Johnston, Sean. *Holographic Visions: A History of New Science*. New York: Oxford University Press, 2006. The historical development of holography is traced from the initial work of Gabor into the twenty-first century. Photographs of some early holograms and the scientific pioneers in this field are included. Gabor's insightful and relentless work led to a new field of discovery that eventually reached maturity.

Kuo, Chung J., and Meng Hua Tsai, eds. *Three-Dimensional Holographic Imaging*. New York: Wiley, 2002. Presents a comprehensive survey of the concepts of three-dimensional holographic imaging and the techniques used in a variety of scientific and engineering applications. Starting with the holographic process invented by Gabor, world-renowned experts in the field provide discussions and examples of the principles and applications of holography that include holographic design and construction of advanced imaging systems.

Saxby, Graham. *Practical Holography*. Bristol, England: Institute of Physics, 2004. Techniques for producing holographic images—from simple single-beam holograms to multicolor art holograms to complex holographic stereograms—are detailed. The principles of holography as developed by Gabor are described, as well as techniques for doing holography, how to set up a holographic laboratory, development of the images, and the methods for displaying holograms. Applications to an array of scientific fields are included.

See also: Emmett Leith.

Ashok Gadgil

Indian physicist

Gadgil introduced a simple, inexpensive method and devices for disinfecting drinking water using ultraviolet irradiation. As a result of his work, a growing line of sustainable products were adapted to the needs of underprivileged people.

Born: 1950; Bombay (now Mumbai), Maharashtra, India
Also known as: Ashok Jagannath Gadgil (full name)
Primary field: Physics
Primary invention: Ultraviolet water disinfection

Early Life

Ashok Jagannath Gadgil (uh-SHOHK JUH-guh-naht GAHD-gihl) was born in 1950 in Dadar, an area of Bombay (now Mumbai). His early education proceeded from Sishu Vihar Montessori School through local Indian Education Society schools to King George High School (now Raja Shivaji High School) in Dadar and two years at Elphinstone College, Bombay. He received a bachelor of science degree in physics (1971) from the University of Bombay, a master of science degree in physics (1973) from the Indian Institute of Technology in Kanpur, and a Ph.D. in physics (1979) from the University of California, Berkeley. His thesis, guided by Professor Arthur Rosenfeld, was on convective heat transfer in building energy analysis.

Life's Work

Dr. Gadgil joined the Lawrence Berkeley National Laboratory (LBNL) in 1980 as a staff scientist in the Energy and Environment Division, Passive Analysis and Design Group. For six months in 1981, he was a visiting research scientist at the Centre Nationale de la Recherche Scientifique (CNRS) at the University of Paris, where he researched the optimization of solar thermal storage systems using phase-change materials. He developed a numerical simulation of time-varying convection and phase change in irregular-shaped cavities, applied to solar energy extraction in buildings.

From 1983 to 1988, Gadgil lived in India, where he became a fellow of the nonprofit Tata Energy Research Institute (TERI) in New Delhi. He researched the technical and economic aspects of energy-efficient solid-fuel stoves and solar thermal systems operating at low temperature. He led research on conservation options for leveling electric lighting load. He also served as technical monitor for projects funded by TERI. His Indian patent applications between 1986 and 1988 describe an energy-efficient Bukhari space heater, a concrete solar water heater, a novel integrated solar water heater, and a solar collector for rural applications based on stabilized mud. The projects that he conducted during this time in India cost some 2.45 million rupees (roughly $200,000) but appear to have set the stage for the breakthroughs that followed.

Returning to LBNL in 1988, Gadgil continued research on indoor airflow and pollutant transport, in part to protect against attack by airborne chemical or biological agents. In 2004-2005, he served in as the Map/Ming Visiting Professor in Civil and Environmental Engineering at Stanford University. As of 2008, Gadgil was senior scientist and deputy director of strategic planning at the Environmental Energy Technologies Division of LBNL, as well as an adjunct professor at the University of California, Berkeley. His team has published more than seventy journal papers and more than one hundred conference publications. His first three U.S. patents included an "Energy-Efficient Device for Exhaust Hoods" (number 5,277,653; January, 1994), a "Detector for Impending Electronic Failures from Aerosol Deposition" (number 5,307,018; April, 1994), and a "Smokeless Ashtray to Capture Side Stream Cigarette Smoke" (number 5,678,576; October, 1997). However, he is best known for the devices related to water treatment.

Gadgil's work on water purification was motivated by personal experiences, such as losing several cousins in childhood to diseases spread by waterborne pathogens. In 1993, a new strain of cholera broke out in southeast India and neighboring countries, killing thousands of people. Gadgil sought an inexpensive way to treat drinking water and remove the pathogens. His first U.S. patent related to ultraviolet water disinfection was for a "UV disinfector with a gravity-driven feed water delivery system, and an air-suspended bare UV lamp" (number 5,780,860; July 14, 1998). An associated Indian patent by Gadgil and Vikas Garud was issued in 2001. The device was effective at killing all the *Escherichia coli*, *Salmonella typhi*, *Vibreo cholerae*, and other pathogens in inlet water in twelve seconds of exposure to the UV radiation, delivering about 120 milliwatts of UV radiation per square centimeter to the water surface.

An "Apparatus for Low-Cost Water Disinfection" (number 6,419,821; July 16, 2002) and a "Method for Low-Cost Water Disinfection" (number 6,602,425; August 5, 2003) by Gadgil and Anushka Dresher incorporates a low-cost ceramic prefilter to improve the clarity of the water, thus reducing the extinction coefficient of the UV, thus improving the efficiency of the irradiation. The "Portable Emergency Relief Water Treatment Unit" (number 6,464,884; October 15, 2002) is intended for use in the wake of natural disasters that disrupt a drinking water supply. The device incorporates an inlet pump, a series of filters to remove particles at progressively finer size, and a pressure gauge and flow meter to monitor the pressure drop and to ensure adequate exposure of the water to the UV radiation. The entire system weighs about 130 kilograms.

These inventions were developed into the UV Waterworks water-disinfection system. The device, using a modified fluorescent lamp to irradiate water with ultraviolet light, eliminates more than 99.9999 percent of pathogenic bacteria and 99.99 percent of pathogenic viruses, typically at a rate of four gallons per minute. UV Waterworks was licensed to WaterHealth International, whose mission is to provide affordable clean drinking water to the developing world.

Gadgil worked on removing arsenic from the groundwater used for drinking in parts of Bangladesh and on a low-cost cookstove for Darfur refugees. In 2005, after visiting the war-ravaged Sudanese region and talking to the refugees, Gadgil and his colleagues and a team of students developed a sheet-metal

MAKING WATER SAFE TO DRINK

Waterborne infectious diseases kill millions of people every year, especially children. Boiling water takes a large amount of energy. Chemicals are expensive, must be regulated carefully, and have side effects. Around 1946, researchers at General Electric found that ultraviolet (UV) radiation from their lamps would kill all of the most harmful bacteria commonly found in water. In fact, UV at 254 nanometers fuses adjacent base pairs in the DNA of bacteria and viruses, rendering the DNA useless to the organism, disabling its ability to generate enzymes for its survival and to multiply and cause disease. Since the bacteria die soon after exposure and cannot reproduce, they pose no threat even if ingested.

More than forty years later, Ashok Gadgil combined his knowledge of basic science with practical experience of what works in the places where most of humanity lives, in order to bring the problem and solution together. The trick was not just to find the optimum wavelength at which to disinfect water, but to design a simple device that would consume little energy, require little maintenance, and survive harsh outdoor conditions for many years, and yet be small, light, portable, and inexpensive. The UV Waterworks device and its derivatives achieve just that. In the summer of 1993, experiments by Gadgil and coinventor Vikas Garud showed that the UV from a 60-watt modified fluorescent lamp could kill bacteria in twelve seconds.

In its most basic form, the device has a tank from which water drips by gravity through a bed, lit by a UV lamp. This mercury-vapor lamp has a quartz tube that transmits UV, instead of a phosphor-coated glass tube that stops UV and emits white light. Little of the energy is wasted as heat or light. The gravity feed avoids the need for pressurized water supply or electric pumps. Instead of a waterproof lamp immersed in water, Gadgil's lamp is simply fixed above the water bed. The power needed is around 40 watts, available from a motorcycle battery, solar cells, or even a hand-cranked generator. More sophisticated versions incorporate multiple filters, pumps, and carts for use in portable drinking water systems for disaster areas. Treating 1.5 liters per minute, a unit can deliver enough safe drinking water for a village of two thousand people for under $2 per person per year, including amortized capital costs. The monetary cost, not to mention the human suffering, avoided by protecting one child from waterborne diseases more than covers that expense. The benefits to humanity from this inspired invention are truly beyond calculation.

cookstove with a cast-iron grate to improve combustion efficiency and energy transfer. The stove uses 55 to 75 percent less wood than an open cooking fire. It is also designed to fit the types of cookware used in the region and to shield the flame from the region's high winds. It is priced at around $15 and has a design life of five years.

Gadgil is a fellow of the American Physical Society and serves on the boards of several nonprofits working to solve pressing problems relating to the environment, health care, and drinking water shortages.

IMPACT

The simple, inexpensive products resulting from Gadgil's inventions have had a significant impact on parts of the world. His UV Waterworks system, a low-maintenance device that consumes only the power of a light bulb, has supplied clean drinking water to some of the least privileged people of the world, a tremendous breakthrough in disease prevention. The mobile water-purification system, small enough to be delivered using a small helicopter, is a lifesaving innovation in the wake of natural disasters or wars. As of 2008, several hundred UV Waterworks systems were in use in several countries, including India, South Africa, the Philippines, Mexico, Ghana, and Honduras. Data show a dramatic reduction in diarrhea, and long-term benefits are expected to include protecting children from stunted physical and mental growth. The Darfur stove reduces the need for refugees to forage for firewood and expose themselves to risk of attacks. A stove that improves combustion efficiency and uses minimal fuel can also make a critical difference to the lives of millions of people, as well as helping to maintain forest cover by reducing the need to cut down trees for firewood. The critical element in these inventions is the knowledge and empathy of the end user's real circumstances.

—*Narayanan Komerath*

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See also: Gordon Gould; Dean Kamen; Maria Telkes.

GALILEO

Italian philosopher, astronomer, and mathematician

Galileo was one of the first Europeans to experiment with and improve the rudimentary telescope and was one of the first to apply it to astronomy. He also created one of the earliest known working microscopes. Deeply involved with observational physics and mechanics, he conducted experiments in gravity, light, sound, motion, and the pendulum, and he invented various objects, including pumps and the hydrostatic balance. History also credits him as one of the earliest advocates of heliocentrism.

Born: February 15, 1564; Pisa, Republic of Florence (now in Italy)
Died: January 8, 1642; Arcetri, Republic of Florence (now in Italy)
Also known as: Galileo Galilei (full name)
Primary fields: Astronomy; mechanical engineering; physics
Primary inventions: Improved telescope; microscope

EARLY LIFE

Galileo (ga-lih-LEE-oh) was born in 1564 to minor gentry in Tuscany under the rule of the Medici family as the grand dukes of Florence. Galileo was the eldest of about six children. His mother was Giulia Ammannati, and his father, Vincenzo, was a prominent lute player, composer, and pioneer of music theory who had also dabbled in the applied mathematics of strings, having published treatises on vibrations of strings. As a musician and theorist, Galileo's father anticipated the harmonic theories of the Baroque, and his technical nature influenced his son's intellectual predilection for science. Galileo's first formal education was at the Camaldolese Monastery at Vallombrosa, south of Florence. His subsequent education was at the University of Pisa, where he had initially enrolled in medicine but was far more interested in mathematics.

LIFE'S WORK

In 1586, at the age of twenty-two, Galileo published a small treatise called *La Bilancetta* (the little balance), in which he added to discoveries of Archimedes about water displacement and specific gravity, weighing materials in air and water. By 1589, Galileo's burgeoning contacts brought him academic stature. Cardinal Francesco Maria del Monte was a clerical courtier of the Florentine Medici and represented Medici interests in Rome to the Vatican. Cardinal del Monte, and especially his mathematician brother Guidobaldo del Monte, helped to secure academic positions for Galileo: first at his alma mater, the University of Pisa, where he was appointed chair of mathematics in 1589, and next at the University of Padua in 1592, where he also taught physics (mechanics) and astronomy. In 1590, following his experiments with motion, he published *De motu* (on motion) at Padua. Galileo was also an apparent houseguest of Cardinal del Monte in Rome at Palazzo Madama on several occasions. Correspondence between the del Monte brothers and Galileo has survived, partly because the urbane cardinal saw himself as much a champion of science as a clergyman.

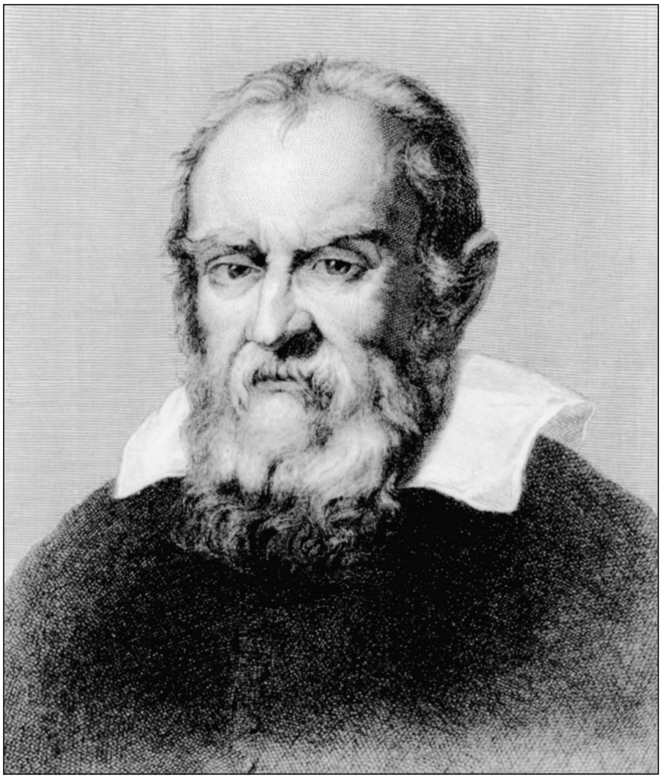
By 1598, expanding on earlier instruments designed by Guidobaldo del Monte and others, Galileo had improved a geometric and military compass for surveyors and for army use. He published on his compass improvements in *Le Operazioni del compasso geometrico et militare* (operations of the geometric and military compass) in 1606. Following Archimedes, whom he much admired, he also invented a thermometer based on buoyancy and designed a related hydrostatic balance. Between 1600 and 1606, Galileo fathered three illegitimate children with Marina Gamba, whom he never married but who later married a Florentine man. Both of Galileo's daughters became nuns.

In the field of physics, Galileo experimented with motion, sound, inertia, and the speed of light. He posited a hypothesis on relativity, setting the stage for later improvements by Sir Isaac Newton and Albert Einstein. In astronomy, beginning in 1609—only a year or so after the likely invention of the telescope in northern Europe, although both Roger Bacon and before him Ibn al-Haytham had possibly pursued lens use for similar purposes—Galileo constructed a telescope and applied it first to land and then to the night sky. He observed and roughly mapped the surface of one side of the Moon, the phases of Venus, at least four moons of Jupiter, Saturn, the Milky Way, and other phenomena. Many of his astronomical discoveries were published in 1610 in his *Sidereus nuncius* (starry messenger). There is also evidence that he constructed one of the first microscopes. His study of sunspots was published in 1613.

Another of Galileo's correspondents and acquaintances from around 1610 onward was Prince Federico Cesi (1585-1630), who in 1603 founded the Accademia

Nazionale dei Lincei, an early scientific academy in Italy whose members were often accused of occultism and opposition to the doctrine of the Roman Catholic Church. Cesi was also a friend of both Cardinal del Monte and Giambattista della Porta, the latter of whom became one of the earliest members of the Lincei academy. At Cesi's palazzo, a Greek scientist named Giovanni Demisiani officially named the "telescope" (from the Greek *tele*, "far," and *skopein*, "to see") at a function in 1611 celebrating Galileo, who became an elected Lincei academy member on that occasion.

With initial patronage from the Barberini family in Rome, Galileo published *Il Saggiatore* (1623; the assayer), a bold text about his philosophy of science wherein he asserted that mathematics was the optimum tool for measuring and expressing truths of nature through physics. Galileo's growing disputes with the Jesuits and Father Orazio Grassi, a capable Jesuit astronomer whom Galileo increasingly criticized in polemic writing, did not help his case for Copernican heliocentrism by greatly alienating the Jesuits.


Galileo. (Library of Congress)

In 1632, Galileo published his polemical *Dialogo sopra i due massimi sistemi del mondo* (dialogue concerning the two chief world systems), in which he compared Ptolemaic geocentrism with Copernican heliocentrism. Although he had been called to Rome in 1616 over his controversial views and prohibited from publicly advancing heliocentric arguments, Galileo still had friends in Rome. His 1632 work was his most strident, a clever literary construction about his views that in some way mocked Pope Urban VIII, who had earlier befriended and defended Galileo when he was still Cardinal Maffeo Barberini. By putting the pope's views in the mouth of the character Simplicio, a simpleton advocate of geocentrism, which he then vigorously attacked, Galileo made himself too visible to leave alone, a heretical loose cannon in the Church's eyes.

Arguably the most famous incident in his life was his 1633 call to Rome by the Inquisition to account for his "Copernican heresy" regarding heliocentrism. He defended his views vigorously but was publicly charged as a heretic and placed under house arrest near Florence for the rest of his life. The popular story of his stamping his foot and muttering "But it does move" is unprovable. Although his writings were banned, he continued to write on such topics as gravity, including such works as his 1638 *Discorsi e dimostrazioni matematiche intorno a due nuove scienze attenenti alla meccanica e i movimenti locali* (discourses and mathematical demonstrations about two new sciences concerning mechanics and local motion). Although later legends are full of anecdotal information, there is no proof that he had actually conducted his experiments with falling objects from the Leaning Tower of Pisa. He did demonstrate the rate of falling objects in other experiments and was able to show the problems with prior Aristotelian ideas on falling bodies in his 1632 work and refined in his 1638 work onward.

Galileo died in 1642, blind and sick, at his house in Arcetri just outside Florence. He was buried in Florence's Basilica of Santa Croce, at first in a small and easily ignored corridor room but later in the main basilica by 1737. It took at least a century before some of his scientific writings were removed from the papal Index of prohibited books, and longer for others. To say the Church was an enemy of Galileo or vice versa, however, is simplistic, as he was far more tolerated—partly because he firmly maintained his Catholicism—than had been the heliocentrist Giordano Bruno, who was burned at the stake as a heretic in early 1600 in Rome. That Galileo's study of motion and the principle of inertia and his longstanding work on gravity had a lasting influence on Newton and later physicists such as Einstein is without question, earning him the deserved title of "father of modern science."

IMPACT

As an important early advocate of what was then called the "Copernican heresy" by the Church, now known as heliocentrism, Galileo was a notable figure of the Scientific Revolution, showing his resolute commitment to challenging dogma by braving the Inquisition's charge of theological error. His famous Pisan anecdotes and other experiments with gravity proved Aristotle wrong and were ultimately indispensable to Newton's formulations of the laws of gravity and inertia. Galileo's contributions to astronomy are derived not only from his improvements to the telescope but also its practical application to many later planetary studies. Building on the work of Archimedes, Galileo's mathematical studies of the parabola and trajectory were important not only for military engineering but also for physics in general. His innovations and his many mechanical applications, pioneering of microscopes and thermometers and seminal studies of mathematical survey, motion, dynamics, and nautical technology, also blazed a trail others would follow. An early exemplar of the attitude of modern science, Galileo was usually willing to correct his previous errors and revise hypotheses and conclusions. His experimental observations and publications claimed and proved that the laws of nature can be stated mathematically, a notion that became a foundation of science. These are just some of the many reasons why Galileo is called the "father of modern science," a title acknowledged by no less than Albert Einstein and Stephen Hawking.

—Patrick Norman Hunt

GALILEO'S TELESCOPE

As author Fred Watson describes in his book *Stargazer* (2004), by mid-1609 Galileo had heard rumors about the new Dutch spyglass patented by Hans Lippershey called a "perspicillum" (from the Latin *perspicax*, "sharp-sighted"), although it is unlikely that Galileo saw a prototype. Being a mathematician, he deduced that the necessary magnification "was the result of the ratio of the focal length of the two lenses." Galileo soon found his own set of preexisting glass lenses and placed them at the right distance from each other in a lead tube. He used soft lead because it could be easily rolled and manipulated to hold the lenses securely. Galileo's telescope used one convex lens, called an objective, which gathers the light coming from the observed object, and one concave lens, the eyepiece; together, these lenses could magnify usually no more than three times. That year, Galileo steadily experimented by producing the shallow parabolic curves needed on glass lenses. Improving on the grinding and polishing of his own lenses and experimenting with the shallow angles and variable distances between the lenses, Galileo soon improved this magnification to twenty times and ultimately to thirty times.

Whereas others had primarily used the telescope for land viewing during the day, Galileo applied the new instrument heavenward at night. Viewing the Moon, probably for the first time ever at such clarity, Galileo noticed its rough spherical surface, pitted with craters and likely chasms. He soon made other important discoveries about the phases of Venus, Jupiter's four largest moons, the Milky Way as a mass of stars, and other astronomical phenomena he quickly published in his *Sidereus nuncius* (starry messenger) in early 1610.

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See also: Archimedes; Aristotle; Roger Bacon; Albert Einstein; Daniel Gabriel Fahrenheit; Otto von Guericke; Christiaan Huygens; Zacharias Janssen; Hans Lippershey; Sir Isaac Newton; Ptolemy; Santorio Santorio; Evangelista Torricelli; Konstantin Tsiolkovsky; An Wang.

ROBERT CHARLES GALLO

American research scientist and biomedical researcher

Perhaps the best-known medical researcher in the United States, Gallo, along with Luc Montagnier at the Pasteur Institute, discovered the human immunodeficiency virus (HIV) and established that this virus causes acquired immunodeficiency syndrome (AIDS). Gallo also developed a blood test for HIV and discovered interleukin-2, the human T-cell growth factor, and the human T-cell leukemia viruses (HTLV-1 and HTLV-2).

Born: March 23, 1937; Waterbury, Connecticut
Primary fields: Biology; genetics; medicine and medical technology
Primary invention: AIDS blood test

EARLY LIFE

Robert Charles Gallo was born to Francis Anton Gallo, a metallurgist, and Louise Mary (Ciancuilli) Gallo. His grandparents were Italian immigrants. In 1948, when Robert was eleven years old, his only sibling, Judy, was diagnosed with childhood leukemia. Even though Judy received treatment and her leukemia went into remission, she died in March, 1949. The loss of his sister would influence Gallo's future career choice. The pathologist who had diagnosed Judy's disease, Marcus Cox, became a family friend and mentor to the young Gallo.

Gallo attended Sacred Heart High School, where he was an avid basketball player. After suffering an injury that prevented him from playing, Gallo spent more time at the hospital with Dr. Cox. This inspired Gallo to become a physician.

Gallo received his undergraduate education from Providence College in Rhode Island, earning a B.S. in biology in 1959. Gallo then attended Jefferson Medical College in Philadelphia and received his medical degree in 1963. Afterward, he completed his internship and medical residency at the University of Chicago, where he worked on the synthesis of hemoglobin.

LIFE'S WORK

In 1965, Gallo went to work as a clinical associate at the National Cancer Institute at the National Institutes of Health (NIH) in Bethesda, Maryland. Since he chose leukemia as his research subject, Gallo spent much of his time caring for cancer patients. Promoted to a full-time research position in 1966, Gallo was made an associate of Seymour Perry, head of the medicine department. Perry studied the nature of white blood cell growth in leukemia patients, and Gallo examined the enzymes that synthesized deoxyribonucleic acid (DNA) in leukemia cells. The passage of the National Cancer Act in 1971 led to the creation of a new Laboratory of Tumor Cell Biology at the NIH, and Gallo was appointed head of this new laboratory.

Intrigued by the possibility that viruses could cause cancer, Gallo studied retroviruses. Retroviruses are ribonucleic acid (RNA) viruses that possess an enzyme called reverse transcriptase, which synthesizes a DNA copy of the RNA genome of the virus. This is the reverse of what occurs in cells, since DNA is used to store genetic information in cells, and an RNA copy of the DNA is used for gene expression. Retroviruses are unusual in this regard because RNA is the molecule used to store genetic information in the virus particle, but upon entry into the cell, a DNA copy is made from the RNA template. Even though many animal retroviruses were known, no human retroviruses had yet to be identified.

In 1976, Gallo and his lab discovered a protein called interleukin-2. Interleukin-2 stimulates a group of white blood cells (called T lymphocytes, or T cells) to grow. T lymphocytes help fight viral infections and stimulate B lymphocytes to synthesize antibodies. More important, T lymphocytes can also be infected by viruses, causing

THE AIDS BLOOD TEST

The AIDS blood test designed by Robert Charles Gallo determines if a person has antibodies against HIV in his or her blood. Antibodies are large proteins made in response to invasion of the body by foreign entities. They are produced by a specific group of white blood cells called B lymphocytes. An antibody precisely fits a specific foreign substance, or antigen. Once secreted by B lymphocytes, antibodies bind to antigens and cause them to clump. Clumped antigens are more easily identified, destroyed, and removed from the body.

If specific antibodies are present in a person's body, they indicate that the person has been exposed to or was immunized against a particular disease. Thus, if someone has antibodies that fit a virus like HIV, the physician knows that the patient has been exposed to HIV. Therefore, positive detection of anti-HIV antibodies indicates that HIV is present in the bloodstream of the patient.

Once Gallo and his colleagues isolated HIV, they were able to grow the virus en masse and isolate external proteins that the immune system would construct antibodies against. Next, they used these viral proteins in an enzyme-linked immunosorbent assay, or ELISA. ELISAs use small vials that have been coated with the viral proteins that the immune system is likely to make antibodies against. Next, a patient's blood serum is applied to the vial. If anti-HIV antibodies are present in the patient's serum, they will bind to the viral proteins that have been immobilized on the surface of the glass vial. After the serum is removed, a second round of special antibodies called secondary antibodies is applied to the vial, and these bind to the immobilized antibodies. The secondary antibodies have an enzyme linked to them that can take a chemical substrate and convert it into something colored. The more secondary antibodies are bound, the darker the color; the darker the color, the more antibodies are bound to the vial surface. The color made by the secondary antibodies is detected by a spectrophotometer.

Today, the entire test is mechanized and is simple and fast. Large numbers of blood samples can be processed in a relatively short period of time at a relatively low cost.

them to become cancerous. With interleukin-2 in hand, Gallo and his coworkers could grow T lymphocytes outside the body in culture and hunt for human T-lymphocyte-specific viruses. This strategy paid off in 1980, when Gallo and his colleagues announced the isolation of a human retrovirus from a leukemia patient that could convert cultured T lymphocytes into cancer cells. He named this virus human T-cell leukemia virus, or HTLV. A second type of HTLV, termed HTLV-2, was isolated from a T-lymphocyte hairy cell leukemia in 1982.

In 1981, clinical descriptions of a new disease among sexually active, gay men, blood transfusion recipients, and intravenous drug abusers appeared. This disease was characterized by a complete breakdown of the immune system and was named acquired immunodeficiency syndrome, or AIDS. In 1981, Gallo attended a seminar by Centers for Disease Control epidemiologist Jim Curran, who spoke about the advancing AIDS epidemic and asked the audience, "Where are the virologists?" Curran was convinced that AIDS was an infectious disease that was probably caused by a new virus. Gallo's work with HTLV-1 and HTLV-2 positioned him to investigate AIDS. Max Essex from the Harvard School of Public Health reminded Gallo that an animal retrovirus called feline leukemia virus could not only cause leukemia but also destroy the immune system. Other work with HTLV-1 showed that it could be transmitted by breast-feeding, sexual intercourse, and blood transfusions, which was very similar to the manner in which AIDS was transmitted. Therefore, Gallo hypothesized that AIDS was caused by a retrovirus.

Throughout 1983, Gallo and his coworkers attempted to isolate the AIDS virus by adding blood from infected patients to cultured T lymphocytes, as he had done with HTLV. This approach did not work, but a member of Gallo's research group named Mikulas Popovic developed a technique that grew multiple samples from several patients on a cultured T-lymphocyte line. An unidentified retrovirus grew in these cultures, and Gallo initially called it HTLV-3. HTLV-3 turned out to be virtually identical to a virus that Luc Montagnier isolated from an AIDS patient in 1983 at the Pasteur Institute in Paris, termed lymphadenopathy-associated virus, or LAV. Even though they were the first to isolate the virus, Montagnier and his group were unable to determine if LAV was the cause of AIDS. However, in 1984, Gallo and his colleagues demonstrated that HTLV-3/LAV (which was later renamed human immunodeficiency virus, or HIV) is the cause of AIDS. Gallo went one step further and created a blood test that could identify antibodies specific to HIV.

The U.S. Patent Office awarded the patent for the AIDS blood test to Gallo even though Montagnier had applied for a patent on an AIDS blood test seven months earlier. The French government sued the U.S. government over the rights to the AIDS blood test, and a war of words broke out between Gallo and Montagnier. This controversy was settled in 1987, when Gallo and Montagnier agreed to share credit for the discovery.

The controversy was rekindled in 1989 when journalist John Crewdson published a lengthy exposé in the *Chicago Tribune* that accused Gallo of stealing Montagnier's work. This led to an investigation by the Office of Research Integrity at the U.S. Department of Health and Human Services, which found Gallo and his colleague Popovic guilty of scientific misconduct. Upon appeal, Gallo and Popovic were cleared of all charges in December, 1993. In 1994, the United States and France renegotiated their agreement that covered the AIDS blood test in order to make the distribution of royalties more equitable.

In 1995, Gallo left the NIH to become the director of the Human Virology Institute at the University of Maryland. That same year, Gallo discovered that chemokines, which occur naturally in the body, can block HIV replication and halt the progression of AIDS. This discovery was the impetus for the development of a class of anti-HIV drugs called the chemokine antagonists/entry inhibitors. In 2001, Gallo announced the development of an HIV vaccine that worked in monkeys. The next step is to create a vaccine for use in humans.

IMPACT

The discovery of HIV by Gallo and Montagnier was the critical first step in identifying the cause of AIDS. The earlier discovery of interleukin-2 by Gallo allowed the growth of cultured T cells that were used to grow the virus and make large quantities of it to develop the blood test. The blood test that resulted from this work convincingly demonstrated that HIV causes AIDS. Even more important, the blood test provided the means to test the blood supply for HIV-contaminated blood and therefore saved untold millions of people from contracting AIDS through the transfusion of HIV-tainted blood. Once the HIV blood test became commercially available, the transmission of AIDS through blood transfusion dropped to almost zero.

In 1985, the cloning and sequencing of the HIV genome identified many potential drug targets. AIDS drug treatments have targeted HIV components and the biological processes they execute. Without the isolation and characterization of this virus, the ability to design such drugs would not exist. Gallo and Montagnier's discovery served as a stimulus that accelerated HIV research and made HIV one of the most heavily studied viruses known to science.

On the downside, the conflict between Gallo and Montagnier dampened the enthusiasm and optimism that surrounded HIV research. Many were appalled that science was subject to human frailties and that scientists could seem so petty. The feud severely undercut the public confidence in science, strained ties between scientists and the AIDS community, and cultivated distrust between many scientists and the press.

—*Michael A. Buratovich*

FURTHER READING

Crewdson, John. *Science Fictions: A Scientific Mystery, a Massive Cover-up, and the Dark Legacy of Robert Gallo*. New York: Back Bay Books, 2002. A book-length treatment of the material covered in Crewdson's *Chicago Tribune* piece. Unfortunately, this book uncovers nothing new, makes more than a few mistakes, and is very biased and unfair toward Gallo.

Gallo, Robert C. "The Early Years of HIV/AIDS." *Science* 298 (2002): 1728-1730. Gallo's brief but interesting reminiscence about how his laboratory helped discover HIV and recognize it as the cause of AIDS.

_______. *Virus Hunting: AIDS, Cancer, and the Human Retrovirus: A Story of Scientific Discovery*. New York: Basic Books, 1991. Gallo's in-depth autobiography that details his own contribution to the discovery of HIV as the cause of AIDS. Much of this book focuses on rebutting the accusations of Crewdson's *Chicago Tribune* article.

Kulstad, Ruth, ed. *AIDS: Papers from "Science," 1982-1985*. Washington, D.C.: American Academy for the Advancement of Science, 1985. A collection of the seminal papers on HIV and AIDS that were published in the internationally recognized journal *Science*.

Montagnier, Luc. "A History of HIV Discovery." *Science* 298 (2002): 1727-1728. Montagnier's recollection of his own contribution to the discovery of HIV.

_______. *Virus: The Co-discoverer of HIV Tracks Its Rampage and Charts the Future*. Translated by Stephen Sartarelli. New York: W. W. Norton, 1999. The first half of the book is Montagnier's autobiography. He describes his AIDS work and is impressively fair to Gallo. The second half is an engaging discussion of HIV and how to fight it.

Prusiner, Stanley B. "Discovering the Cause of AIDS." *Science* 298 (2002): 1726-1727. A highly regarded neuroscientist who did not directly participate in the discovery of HIV briefly recounts the development of the clinical picture of AIDS and the discovery of HIV as the cause of AIDS.

See also: Gertrude Belle Elion; Kary B. Mullis; Jonas Salk.

BILL GATES

American computer scientist and businessman

Gates cofounded the Microsoft Corporation, the world's largest PC software company, and he helped develop the Windows operating system, word processors, and spreadsheets. He also cofounded the largest charitable organization in the world, the Bill and Melinda Gates Foundation.

Born: October 28, 1955; Seattle, Washington
Also known as: William Henry Gates III (full name)
Primary field: Computer science
Primary inventions: Windows operating system; Microsoft software company

EARLY LIFE

William Henry "Bill" Gates III was the second of three children born to William Henry Gates II, an attorney, and Mary Maxwell Gates, a University of Washington regent. Small in stature and socially awkward, Gates grew up in a loving and intellectually stimulating home. In seventh grade, he transferred to Lakeside School, an elite institution in Seattle where he became acquainted with other students and teachers interested in computer programming. In 1968, they began reading computer manuals for large mainframe computers, and Gates began learning programming languages such as BASIC and FORTRAN. Using a Teletype machine connected by telephone to a mainframe computer in a local General Electric office, Gates wrote his first software program, a game of tic-tac-toe, at the age of thirteen.

Students had to pay for expensive programming time to run their software on mainframe computers, so Gates and several friends (including Paul Allen, a future business partner) took programming jobs in the summer, earning money as well as free computer time. The young entrepreneurs formed the Lakeside Programming Group and wrote payroll and traffic data programs, among other projects.

In 1973, Gates enrolled at Harvard University as a prelaw major. He would often skip classes and cram just before a test. In 1975, the Altair 8800 microcomputer was released by Micro Instrumentation and Telemetry Systems (MITS). Allen convinced Gates to join him in writing a BASIC program for the new computer. After discussing it with his parents, Gates left Harvard in his junior year to form the software company Micro-Soft, based in Albuquerque, New Mexico. The company's name was changed to Microsoft in 1976.

Bill Gates at a press conference in September, 1997, to introduce Microsoft's Internet Explorer 4.0 Web browser. In the late 1990's, Microsoft vied with Netscape for Internet market share. (AP/Wide World Photos)

LIFE'S WORK

In the 1970's, programmers often shared their programs free of charge. From its beginning, Microsoft argued that software was intellectual property that ought to be protected by copyright. As faster microchips were developed, companies such as Apple Computer, Radio Shack, and Commodore began to sell small computers that required increasingly sophisticated software. Microsoft began to sell its BASIC program to some of these companies as word processors, graphics programs, and spreadsheets began to be developed.

Initially, Gates wrote the computer software and also ran the business. In 1976, he moved Microsoft from Albuquerque to Bellevue, Washington, a Seattle suburb. The company had twelve employees at that time. Gates believed that the personal computer (PC) was going to become increasingly important, so software such as word processors needed to be developed along with better operating systems. Gates hired a college friend, Steve Ballmer, to promote and run the business side of Microsoft.

In 1980, International Business Machines (IBM), the dominant producer of mainframe computers, decided to enter the PC market. IBM hired Microsoft to write its operating software, called the Microsoft Disk Operating System (MS-DOS), and Microsoft received a royalty for each computer sold. Microsoft was also entitled to sell its software to other companies. By the end of 1982, the company had sold about $32 million worth of software. Microsoft had about two hundred employees at this time. That year, Microsoft released a spreadsheet called Multiplan. In the spring of 1983, the company released Word, one of the first word processors to display text on screen as it would appear on paper. Microsoft expanded rapidly during this period, opening offices overseas, developing hardware, and entering the publishing arena.

In the early 1980's, Microsoft began developing an operating system called Windows, which provided a graphical user interface that allowed computer users to interact with several open programs by using a mouse. This was a risky move for Microsoft because IBM was more interested in developing its own operating system. The first version of Windows was released in 1985 but was not successful; few programs had been written to run on Windows, and it had a number of bugs. Nevertheless, Microsoft sold $140 million in products that year. By 1987, IBM had adopted Windows as its new operating system.

Microsoft had its initial public offering on March 14, 1986, closing at about $28 per share that day. Many of the company's early employees became multimillionaires or billionaires overnight. In 1987, Microsoft released Windows 2.0 and the Excel spreadsheet and began work on CD-ROMs. Windows 3.0 was launched in 1990, and it became an instant success. More than 4 million copies of the version had been sold by the end of 1991. In addition, Word 2.0 and CD-ROM titles were released that year. In 1993, Windows NT—based on Windows 3.1 (1992)—was released. With this 32-bit operating system, businesses could run high-end engineering and scientific applications. Other Windows versions released over the years include Windows 95, Windows 98, Windows ME (2000), Windows XP (2001), and Windows Vista (2007).

The Windows operating systems helped Microsoft to become a monopoly. In 1995, Microsoft released its Internet Explorer, bundled with Windows, to compete with Netscape for Internet market share. In 1998, the U.S. Department of Justice and twenty state attorneys general commenced an antitrust suit against Microsoft, charging that Microsoft bullied other companies into using its Web browser in order to thwart competition. Gates did not testify at the trial, but in a videotaped deposition he claimed that he was unaware of key business dealings related to the charges. A number of journalists commented that Gates was evasive during the deposition and lacked credibility. In 2000, Microsoft was judged to be a monopoly and required to break up into two separate companies. Microsoft soon appealed and was allowed to remain as one company. By this time, however, Gates's reputation had been somewhat sullied.

During the 1990's, Gates started to focus on both family and philanthropy. In 1994, he married Melinda

MICROSOFT BASIC

In the early 1970's, Bill Gates was one of the first persons to see the need for personal computer (PC) software that would allow PCs to operate efficiently. Following the release of the 8008 microprocessor chip by Intel in 1972, Gates and his friend Paul Allen wrote software for the chip to measure traffic flow along streets. In 1975, the Altair 8800 microcomputer (which had neither a keyboard nor a monitor) was released by Micro Instrumentation and Telemetry Systems (MITS). The Altair was based on Intel's 8080 microprocessor, which had ten times the performance of the 8008. That year, Gates and Allen left Harvard to start their new software company, Micro-Soft (renamed Microsoft in 1976), to write a BASIC program for the Altair. The young men hired several students at Harvard to write some parts of the program. MITS found a number of bugs in the program, so the Microsoft team spent a lot of time fixing the software. In 1976, Gates moved Microsoft to Albuquerque, New Mexico, where MITS was located. The team wrote various versions of BASIC to be used with the different computers then available. The BASIC programs were sold at a low cost since Microsoft believed that it would profit from the large number of computers sold with the programs.

Gates and his employees often worked up to sixteen hours a day while they developed the software for Microsoft. Microsoft BASIC was the founding product of the company, which later developed such programs as MS-DOS and the Windows operating systems.

French, with whom he had three children. The couple established the Bill and Melinda Gates Foundation in 2000, the year Gates stepped down as chief executive officer of Microsoft and was replaced by Ballmer. Gates officially retired from Microsoft in the summer of 2008. Donations from the Gates Foundation have been allocated to such causes as minority scholarships, Gates Cambridge Scholarships, and AIDS prevention.

IMPACT

In the late 1970's, Gates began developing operating system software for the fledgling PC industry that allowed for innovation in both software and hardware. His user-friendly Windows operating system made it easier for average individuals to use computers. During the 1980's, Gates was responsible for marketing Microsoft's wide range of products, and he met with senior managers to evaluate Microsoft's approach to product development. His business acumen helped build Microsoft into the world's largest PC software company. As a philanthropist, Gates has used his wealth and influence to bring attention to a wide range of social issues.

—*Robert L. Cullers*

FURTHER READING

Boyd, Aaron. *Smart Money: The Story of Bill Gates*. Greensboro, N.C.: Morgan Reynolds, 1995. Aimed at a juvenile audience, this book looks at Gates's younger years and his career at Microsoft. Includes descriptions of the many problems that Gates faced with Microsoft as well as his abusive behavior toward some of his subordinates.

Edstrom, Jennifer. *Barbarians Led By Bill Gates: Microsoft from the Inside—How the World's Richest Corporation Wields Its Power*. New York: Henry Holt, 1998. Offers a critical view of Microsoft since the 1980's.

Gates, Bill. *The Road Ahead*. New York: Penguin Books, 1995. Gates reflects on the status of the "information highway" twenty years after he began working with Paul Allen. Includes Gates's predictions for the future.

Stross, Randall E. *The Microsoft Way: The Real Story of How the Company Outsmarts Its Competition*. New York: Basic Books, 1997. Argues that Microsoft's success is due in part to the company's hiring intelligent workers and giving them large stock options, as well as fostering a creative atmosphere. The author interviewed Bill Gates and Microsoft employees and had access to Microsoft files.

See also: John Presper Eckert; Federico Faggin; Ted Hoff; Jack St. Clair Kilby; Leonardo da Vinci; Robert Norton Noyce; William Shockley; An Wang.

RICHARD GATLING

American engineer

Gatling invented the first practical machine gun, which greatly enhanced the ability of small groups in warfare to overcome larger ones.

Born: September 12, 1818; Maneys Neck Township, North Carolina
Died: February 26, 1903; New York, New York
Also known as: Richard Jordan Gatling (full name)
Primary fields: Agriculture; military technology and weaponry
Primary invention: Gatling machine gun

EARLY LIFE

Richard Jordan Gatling was born in a log cabin in rural North Carolina, where he lived for his first six years. In 1824, the family moved into a two-story house built by his father, Jordan Gatling, on a large tract of land that would become a successful plantation. In 1835, his father patented a cotton planter and a rotary cultivator. Richard Gatling had six siblings: three sisters, one of whom died in infancy, and three brothers. All the boys attended primary school at Buckhorn Academy, a classical boys' school run by a nearby church. Thereafter, he worked on the family farm. The family was well respected for its success at farming and business, although Gatling's reclusive father was not personally popular. For a while, the young Gatling served as a clerk in the Murfreesboro law office of his uncle Lewis M. Cooper.

At age seventeen, Gatling invented a screw propeller, but his father refused to allow him travel to Washington, D.C., to file a patent claim. When his father finally relented, Gatling arrived in D.C. only to find that John Ericsson (who would eventually build the Civil War ironclad the *Monitor*) had been granted the screw propeller patent a few months earlier. At age nineteen, Gatling became a schoolteacher at an "old field school" (a small, primitive schoolhouse in a field or clearing). While continuing his teaching career, he opened a general merchandise store in 1840.

Gatling's 1841 marriage to a woman from Winston-Salem, North Carolina, was annulled because of the objections of the bride's father. Gatling eventually married Jemima Sanders of Indianapolis in 1854. As a wedding gift, Gatling received a slave, Rachel Stepney, from his father-in-law. Gatling freed her, and she chose to work for the Gatlings as a cook and housekeeper for the rest of her life.

LIFE'S WORK

Gatling's first patent was issued in May, 1844, for a seed sower that planted in straight rows. After the patent was granted, he moved to St. Louis, where he turned the seed sower into a wheat drill and began to make a small fortune. While on a marketing trip, he contracted smallpox and spent three months in 1845-1846 in Pittsburgh in a pesthouse—a place where people with contagious illnesses were quarantined, and where they often died. He survived, and for the rest of his life he wore a beard to cover his pockmarks. In 1847-1849, he attended Indiana Medical College, and then Ohio Medical College. His purpose was not to practice medicine but simply to learn how to protect his own health.

Gatling obtained eight more agricultural patents, including a double-acting hemp break in 1847 and a rotary plow in 1861. Watching the sick and wounded returning home from the first months of the Civil War, he began work on a gun that he hoped would do the work of many soldiers and thereby reduce the number of soldiers needed. The design combined ideas from his father's rotary cultivator and from his own seed sower: Cartridges dropped into the firing chambers from a hopper, just as seeds dropped to the ground from a hopper.

In 1718, James Puckle had patented "A Portable Gun or Machine called a Defence." The Gatling was also preceded by the DeBrame Revolver Cannon (patented 1861), the Ager "Coffee Mill," and various other primitive machine guns. However, Gatling's design, patented in November, 1862, was far superior. He built a half-dozen machine guns in November-December, but the factory and all the guns were destroyed by Confederate arson. Thereafter, he made more guns at another factory, but the U.S. Army was not interested, for the chief of the U.S. Army Department of Ordnance, Brigadier General James W. Ripley, fiercely opposed new guns. Gatling was also dogged by suspicion that his factory, located in Cincinnati, aimed to sell guns to both sides in the war. Federal agents wrongly claimed that he was a member of the Knights of the Golden Circle, a pro-Confederate secret society.

Richard Gatling found other buyers. *The New York Times* bought three of his guns and used them during the July, 1863, draft riots in New York City. While other employees stood ready with rifles, the paper's owner and editor each manned one of the Gatlings, deterring a mob that was threatening the building. Following a personal demonstration from Gatling, Major General Benjamin Franklin Butler bought twelve of the guns for $1,000 each from his personal funds. He probably used them in the siege of Petersburg, Virginia, which lasted from June, 1864, to April, 1865.

The commercial breakthrough came in 1866, when the U.S. Army ordered one hundred Gatling guns. Gatling arranged for Colt's Patent Fire Arms Manufacturing Company to build the guns at its Hartford factory, where all American-made Gatlings were thereafter produced. The next year, the Russians bought one hundred, along with a production license. By the time of the Russo-Turkish War of 1877-1878, the Russians had at least 400 Gatlings. In response to Russian armament, the Ottoman military had purchased 230 from E. A. Paget, an Austrian licensee of Gatling. In 1874, the British bought a ten-barrel version. Later, the Royal Navy bought a .65-caliber model. The licensed British manufacturer, Sir William Armstrong and Co., did a thriving business with many nations.

Richard Gatling was elected the first president of the American Association of Inventors and Manufacturers in 1891 and held the post for the next six years. In 1893, he produced an electric motor-driven gun. The ten-barrel model could fire 3,000 rounds per minute, but not until the Cold War did military strategists find a practical use for such an astounding rate of fire. Gatling's last firearms invention, in 1895, was a mechanism to use gas pressure from the gunpowder explosions to rotate the barrels. This made the Gatling machine gun into a true automatic firearm. However, the gas-powered Gatling was not adopted by any military force. The single-barreled (and therefore much lighter) automatic Maxim gun was the new weapon of choice. In 1911, the U.S. Army declared the Gatling gun obsolete, long after most other nations had done so.

Because of Gatling's ill health and financial problems, he and his wife sold their Hartford mansion in 1897. Competition from other manufacturers, including Maxim, had reduced Gatling's income, and his fortune had been lost to bad investments in real estate. The couple moved to St. Louis, where Gatling continued to invent. His forty-third and final patent was a motorized plow (1902). Because of his ill health, the couple went to stay with their daughter's family in New York City. Gatling died a few weeks later, having spent the last day of his life at the offices of *Scientific American*, which revered Gatling as a self-taught inventive genius, and which had featured him in many articles. Among people who knew him personally, he was highly regarded for his kindness, gentleness, and decency.

IMPACT

Most of the world's armies and navies bought Gatlings during the latter part of the nineteenth century. The British were especially enthusiastic and used them with great effectiveness in the 1879 Anglo-Zulu War and the 1882 suppression of the Urabi Revolt in Egypt. The U.S. Army used them in Indian wars. The presence of Gatlings deterred violent resistance to the 1893 U.S. takeover of Hawaii from Queen Liliuokalani.

Gatling made the first machine gun that worked well enough to be a suitable combat weapon, but the gun's direct impact was somewhat limited. Because Gatlings were cumbersome (usually about one thousand pounds), they were typically deployed to defend a fixed position, such as a fort or bridge. The gun also could jam, or suffer a disastrous explosion, if the gunpowder in a defective ammunition cartridge was delayed in its explosion by a fraction of a second. (This is called a "hang fire.") By the time Gatling solved the problem in the 1890's, the Gatling gun was already being supplanted by the automatic Maxim gun, which was immune to jamming from a hang fire.

During the Spanish-American War, U.S. lieutenant John Henry Parker figured out how to use Gatlings offensively: using one gun to support the advance of the next gun, so that the guns leapfrogged ever closer to the enemy position. In the 1898 Battle of Santiago, the famous charge of Theodore Roosevelt and his Rough Riders up San Juan Hill was supported by Parker's Gatling battery, whose three guns fired 18,000 rounds in the eight-minute assault. Atop San Juan Hill, the Gatlings helped the Americans repel two Spanish counterattacks.

Although ignored during the world wars, the Gatling became the design foundation for General Electric's Vulcan gun, a multibarrel electric machine gun, first produced in 1956, and widely used during the second half of the twentieth century in U.S. airplanes, helicopters, and antiaircraft defenses. Today, new electric Dillon Aero Gatling miniguns are used on American, British, and other nations' helicopters, vehicles, and naval vessels.

—David B. Kopel

THE GATLING GUN

The Gatling gun had several gun barrels, each with its own bolt and firing pin. Multiple barrels were necessary because a single barrel would have been destroyed by the heat from so many gunpowder explosions in such a short period of time. The barrels were rotated around a central arbor by a hand crank. The first Gatling had six barrels, although many later models had ten barrels, and the principle allowed for any number of barrels. At the end of the crank handle was a small pinion gear, which engaged a larger ring gear that was attached to the central arbor.

When a barrel was at the top of the circle of rotation, the bolt was open, and a cartridge was dropped in from a hopper. As that barrel rotated, its bolt was closed, and the firing pin was cocked. At the bottom, the spring-loaded firing pin was released, and the cartridge was fired. When the barrel rotated again, the bolt would be opened, and the empty cartridge case extracted. A simple fixed cam controlled the loading and firing. The cam follower would open and close the bolt.

The original 1862 design used percussion cartridges, in the .58-caliber musket. In 1865, Richard Gatling switched to metallic cartridges, which were vastly easier to load. (The 1862 design had a more complicated loading and unloading mechanism than the one described above.) While the 1862 model could fire 200 rounds per minute, the 1865 model could achieve 600 rounds per minute. (A round is one cartridge.)

In 1871, Gatling made the gun much more effective with a refinement that allowed the gun's aiming point to be moved laterally, thus vastly widening the gun's field of fire. He also changed the crank so that the gun would automatically have some slight oscillatory lateral motion. The two changes made the Gatling effective at spray fire. A "Camel gun," mounted on a special saddle, was introduced in 1874.

Richard Gatling developed more than thirty versions of the gun, and it was produced in many different calibers. Today, the terms "machine gun" and "automatic" are often used as synonyms, but the Gatling illustrates the difference. The Gatling was the first successful machine gun, but because it was powered by the arm of the gunner, it was not an automatic.

Further Reading

Berk, Joseph. *Gatling Gun: Nineteenth Century Machine Gun to Twenty-first Century Vulcan*. Boulder, Colo.: Paladin Press, 1991. The first part of the book provides excellent technical descriptions of the nineteenth century Gatlings. The second part details how the Gatling design was updated and improved to produce the Vulcan gun, and describes the many different configurations of the Vulcan gun.

Hughes, James B. *The Gatling Gun Notebook: A Collection of Data and Illustrations—Gatling Guns, Component Parts, Nomenclature, Mounts, Ammunition and Accessories, Makers, Users and Serial Numbers*. Lincoln, R.I.: Andrew Mowbray, 2000. Excellent assembly of primary documents from the nineteenth and early twentieth centuries. Much of the book consists of line drawings carefully copied from crumbling, yellowed originals. Extensive detail on purchases of the Gatlings and on the various calibers and other details of the different versions produced for different nations.

Keller, Julia. *Mr. Gatling's Terrible Marvel: The Gun That Changed Everything and the Misunderstood Genius Who Invented It*. New York: Viking Press, 2008. Beautifully written biography by a Pulitzer Prize-winning columnist for the *Chicago Tribune*. Much of the text puts Gatling in the broader context of nineteenth century America, an age whose virtues Richard Gatling embodied.

Stephenson, E. Frank, Jr. *Gatling: A Photographic Remembrance*. Murfreesboro, N.C.: Meherrin River Press, 1993. Superb collection of photographs, old documents, and biographical information about Gatling and his family. Compiled by an amateur historian who grew up near the house where Gatling was raised.

See also: John Moses Browning; Samuel Colt; Hiram Stevens Maxim; John T. Thompson.

JOSEPH-LOUIS GAY-LUSSAC

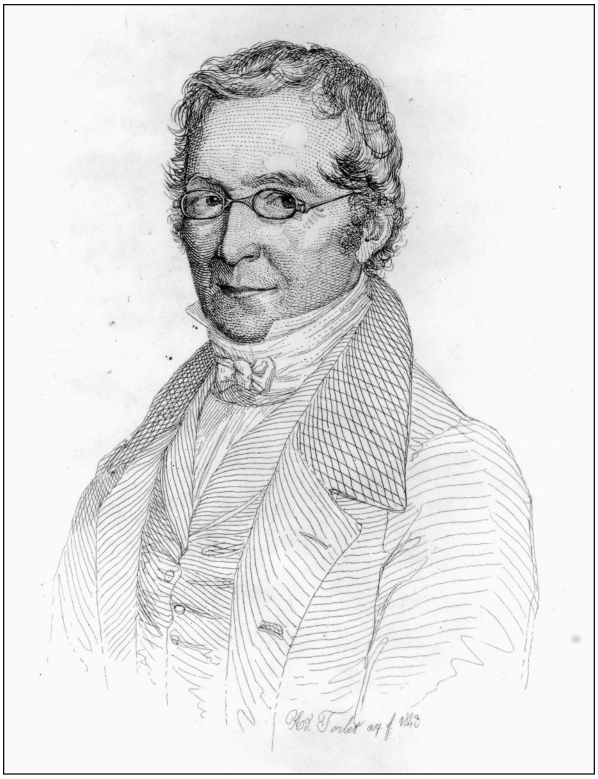
French chemist and physicist

Gay-Lussac was responsible for significant advancements in the fields of industrial and analytical chemistry, pioneering new techniques and apparatuses for the synthesis, isolation, and study of numerous chemical elements and compounds.

Born: December 6, 1778; Saint-Léonard-de-Noblat, France
Died: May 9, 1850; Paris, France
Also known as: Joseph-Louis Gay
Primary fields: Chemistry; physics
Primary inventions: Gay-Lussac tower; Charles's law

Early Life

Joseph-Louis Gay-Lussac (JOH-sehf Lew-EES GAY LOO-sahk) was born in 1778 in the village of Saint-Léonard-de-Noblat in the Limousin region of France. Due to the political instabilities of the time, Gay-Lussac was homeschooled by tutors in his formative years, but he relocated to Paris in 1794 to attend boarding school. There he received a rigorous instruction in the mathematics and science of the time, before being admitted to the prestigious École Polytechnique (polytechnic school) in 1797. After three years of study, he graduated and was due to attend the École Nationale des Ponts et Chaussées (national school of bridges and roads), as



Joseph-Louis Gay-Lussac. (Library of Congress) was typical for engineers at the time, when the eminent scientist Claude Louis Berthollet, who had recently taken a professorship at the École Polytechnique, had need of an assistant. Gay-Lussac was offered the position, and he thus began his career as an experimental chemist.

The appointment under Berthollet allowed Gay-Lussac to interact with such great scientists of the time as the mathematicians Pierre-Simon Laplace and Joseph Fourier. In 1802, Gay-Lussac was also appointed demonstrator for one of Antoine Lavoisier's contemporaries, Antoine François, comte de Fourcroy. At this time, he began his own research into the properties of gases, culminating in 1802 with the publication of a paper detailing the relationship between volume and temperature of gases. Gay-Lussac was now twenty-three years of age and at this time met a young lady, Josephine Rojot, who would eventually become his wife.

THE GAY-LUSSAC TOWER

During the latter part of the eighteenth and early nineteenth centuries, the Western world was undergoing radical change through industrialization. In France, this revolution was aided by the rise to power of Napoleon, who was a great patron of the sciences. Joseph-Louis Gay-Lussac's most productive years coincided with these momentous times, and his impact upon both the theoretical and practical advancement of industry and the sciences is clearly evident. One area in which he made a significant contribution was the industrial-scale preparation of sulfuric acid. In the 1800's, the standard procedure was the so-called lead chamber process, whereby sulfur dioxide (SO_2) and oxygen (O_2) gases, the latter sourced from air, were heated in a lead chamber. The sulfur trioxide (SO_3) formed in the reaction was dissolved in water (H_2O), giving sulfuric acid (H_2SO_4). Metal nitrates were introduced during the process, which on heating released nitrogen oxide gases that catalyzed the reaction. Prior to Gay-Lussac's involvement, these catalysts were vented to the atmosphere once the reaction was complete.

Frustrated by this inefficient methodology, he set about the task of their capture and ultimate recycling. Gay-Lussac knew from laboratory studies that nitrogen oxides reacted with sulfuric acid (the very product from the lead chamber process) to form nitrosulfuric acid ($NOHSO_4$). Extending this knowledge to the industrial scale, he built large towers known as "Gay-Lussac towers" into which sulfuric acid was pumped. When the gaseous products from the lead chamber process were vented through the tower, the nitrogen oxides were effectively captured by reacting with the acid therein. Ingeniously, the towers were filled with small coke balls that became coated with the liquid sulfuric acid, thus vastly increasing the surface area for reaction with the gaseous nitrogen oxides.

Once formed, the nitro-sulfuric acid was collected and decomposed back into sulfuric acid and nitrogen oxides. Gay-Lussac proposed that this be achieved using high-temperature steam, however his process did not prove effective, as the steam tended to dilute the sulfuric acid formed. The British scientist John Glover suggested an alternate method involving what became known as a "Glover tower." The nitro-sulfuric acid from the Gay-Lussac tower was allowed to react with sulfuric acid at high temperatures in the Glover tower, which ultimately afforded the reclamation of the nitrogen oxides.

In the twentieth century, the lead chamber process was succeeded by the contact process. Nevertheless, Gay-Lussac's contribution, when combined with that of Glover, provided a great improvement upon existing technology of the time.

LIFE'S WORK

In the initial years of the nineteenth century, chemistry was still an emerging discipline. Antoine Lavoisier had published his *Treatise of Elementary Chemistry* relatively recently, in 1789, and John Dalton was yet to fully realize his atomic theory of matter. In this exciting time of discovery, the young Gay-Lussac found inspiration in many of his contemporaries, including Jean-Baptiste Biot, Louis-Jacques Thénard, and in particular Alexander von Humboldt and Claude Louis Berthollet. Gay-Lussac's first major contribution to the sciences was a study in 1802 of the thermal expansion of gases. He noted a linear relationship between the volume and temperature of a fixed amount of gas under constant pressure; this became known as Charles's law, as Gay-Lussac referenced unpublished work by Jacques Charles in the 1802 publication.

Expanding upon this line of study, Gay-Lussac made improvements to existing thermometers and barometers, and along with his friend Biot he made balloon ascents in order to take accurate pressure and temperature measurements of the upper atmosphere. These high-altitude (up to seven thousand feet) investigations led Gay-Lussac to notice inaccuracies in the methods used by von Humboldt to ascertain the constituents of air during 1799-1804. The two scientists met and quickly became both friends and colleagues, taking a trip to Italy and Germany together to investigate variations in magnetic forces at different latitudes in 1806.

After spending the winter of 1806 with von Humboldt, Gay-Lussac returned to Paris in the spring of 1807, at which time he took a professorship at the École Polytechnique. Soon after, Berthollet, who had become wealthy under the patronage of Napoleon Bonaparte, formed the most important scientific society of the age, the Société d'Arcueil. Some of the brightest scientists of the time were invited to congregate and study at Berthollet's expense. Gay-Lussac was one of the first members of the circle, and he published the results of his and von Humboldt's magnetic studies in the first volume of the journal published by the society.

In 1808, Gay-Lussac showed that in the reaction between chlorine and hydrogen gases, equal volumes of the reactants are consumed with no excess of either remaining. Also, one volume of nitrogen and three equivalent volumes of hydrogen combine to yield two volumes of ammonia. These and other previously reported data he summarized in the "law of combining volumes" for gases, which stated that when gaseous elements or compounds react, the volumes involved are always simple whole-number ratios.

At a similar time, Sir Humphry Davy reported the synthesis of the metals sodium and potassium from sodium or potassium hydroxide, respectively, using an electrolytic method that was subsequently employed in industry. Gay-Lussac, in collaboration with Louis-Jacques Thénard, devised a higher-yielding method for the preparation of these metals whereby they were distilled at high temperature from a mixture of their carbonates and carbon. Gay-Lussac's interest in industrial processes also extended to the production of sulfuric acid via the lead chamber process, which was the standard in the 1800's. He invented an addition to the existing apparatus that made the overall process far more efficient. This addition became known as the Gay-Lussac tower.

In 1829, Gay-Lussac was appointed the director of the Assay Bureau at the Paris Mint. The French minister of finance was concerned by inconsistencies in the method of "cupellation" used to assess the purity of silver samples at the time. In response, Gay-Lussac devised a new technique, published in 1832, whereby the sample was dissolved in nitric acid and titrated against a standard salt solution. The procedure was possible thanks to his improvement upon existing apparatuses used for the measurement and transfer of volumes of liquids. A glass "burette" had previously been utilized by François-Antoine-Henri Descroizilles; however, his was essentially just a graduated cylinder, which lacked the accuracy required for the silver assay procedure. Gay-Lussac's introduction of a pressure-equalizing side arm to the apparatus allowed the pouring of liquids without spillage. Gay-Lussac also devised the modern form of the pipette, which employs a glass cylinder with thin inlet and outlet pipes and a fat central portion into which the majority of the desired liquid is drawn. The thin section of glass at the outlet of the tube allows for accurate measurement of the volume of the liquid contained therein.

In 1835, Gay-Lussac published a new method for the determination of the chlorine content in "bleaching powder," a mixture of chlorine and slaked lime. When left in unsealed containers, the powder would decompose, releasing chlorine and losing its bleaching ability. Gay-Lussac's new method allowed the state of decomposition to be determined and spoiled powders to be discarded.

In the 1840's, Gay-Lussac made fewer contributions to physics and chemistry, though he remained a highly respected figure until his death on May 9, 1850, as a result of dropsy (edema). His grave lies in Père Lachaise Cemetery in Paris.

Impact

Whereas Gay-Lussac is remembered primarily for his studies of gases, the results of which appear in every concise introduction to chemistry and physics published today, he was also responsible for significant progress in the practical application of chemical theory, both on laboratory and industrial scales. His practical advances have in some cases been superseded by even more effective processes in modern times; however, his initial improvements were insightful and invaluable at the time of their implementation.

The chemical industry in the 1800's suffered from problems of inefficiency and inaccuracy. One example was the production of sulfuric acid via the lead chamber process, upon which Gay-Lussac made significant improvements. The lead chamber process has since been replaced by the contact process; however, at the time, Gay-Lussac's ability to apply theoretical understanding of chemistry to practical application was remarkable. Similarly, the novel procedure outlined by Gay-Lussac for the isolation of sodium and potassium metals was used commercially for more than fifty years until such time as more advanced electrochemical methods were available.

Gay-Lussac's legacy extends to laboratory-scale chemical procedures, particularly in the determination of chemical composition. He was responsible for a number of highly accurate assays and for the invention of sensitive equipment required to perform them. Most notable are his silver assays and his improvements upon existing techniques for combustion analysis of organic compounds, procedures that are still followed today. Subsequent to his death, improvements were made upon his apparatus designs in some cases, including the alternate form of the burette used by Friedrich Mohr that involved a glass tube ending in a rubber outlet with a releasable clip.

Membership of the Société d'Arcueil provided Gay-Lussac with both finances and a nurturing environment in which to carry out his studies. It was during his lifetime, and partly due to his studies, that chemistry was recognized as an independent discipline. During this period, the critical thinking used in what is now called the scientific method was refined by figures such as Gay-Lussac and his peers, leading to publications that are now considered to be model examples of scientific investigation. In his later years, Gay-Lussac ensured the continuation of this style of research by mentoring and influencing future chemists such as Justus Liebig, Henri Victor Regnault, Edmond Frémy, Théophile-Jules Pelouze, and Pierre Jean Robiquet.

—*Bruce E. Hodson*

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See also: Robert Wilhelm Bunsen; Joseph Priestley.

HANS GEIGER

German physicist

Geiger coinvented the Geiger-Müller tube, the basis for the Geiger counter, which is used to check an article for radiation. Geiger also devised and conducted the experiments that led Ernest Rutherford to the discovery that the atom is a tiny nucleus surrounded by electrons.

Born: September 30, 1882; Neustadt an der Haardt (now Neustadt an der Weinstrasse), Germany
Died: September 24, 1945; Potsdam, Germany
Also known as: Johannes Hans Wilhelm Geiger (full name)
Primary field: Physics
Primary invention: Geiger-Müller tube

EARLY LIFE

Johannes Hans Wilhelm Geiger (yoh-HAHN-ihs HANZ VIHL-hehlm GI-gur) was born in Neustadt an der Haardt, Germany, on September 30, 1882, the oldest of five children (two boys and three girls). His father, Wilhelm Ludwig (1856-1943), was a philologist who taught in the secondary schools in Neustadt and Munich. From 1891 to 1920, he was a professor at the University of Erlangen. The young Geiger went to school at Erlangen Gymnasium and graduated in 1901. He had shown an aptitude for physics in school. After a mandatory year of military service, he began his studies in physics and mathematics at the University of Munich. He took his preliminary examinations in 1904 and began his research at the Friedrich-Alexanders University at Erlangen, where Eilhard Wiedemann was his mentor.

Geiger's dissertation was on electrical discharges through gases. In July, 1906, he defended his thesis and was awarded his doctorate. He moved to the University of Manchester in England to work as an assistant to Arthur Schuster, head of the Physics Department and an expert on gas ionization. When Schuster left in 1907, he was replaced by Ernest Rutherford. Geiger stayed to work as Rutherford's assistant.

LIFE'S WORK

Rutherford had done extensive work in radioactivity and was awarded the Nobel Prize in Chemistry in 1908 for his work. He was interested in investigating the interior of the atom. It was known that certain isotopes emitted alpha rays, and Geiger and Rutherford began to study alpha particles and how they could penetrate thin films. The anticipated result was that the alpha particles would go straight through thin films with a small deviation of path, a small angle of scattering.

The prevailing theory of the atom at the time was the "plum pudding" model of Joseph John Thomson: Protons were mixed into a sea of electrons like plums in the English dessert. The alpha particles passing through this pudding should have a small angle of scattering because they are deflected by many particles close to the size of an alpha particle. Geiger designed the experiment so that the alpha particles would hit a zinc sulfide screen after passing through the gold foil. When an alpha particle hits the zinc sulfide screen, a flash occurs. The experiment required many hours of watching the screen for light flashes. The results were that most of the alphas were not deflected, instead traveling straight through the foil. Geiger suggested that a young physicist, Ernest Marsden, check for wide-angle deflections. When these deflections were found, the plum pudding theory was doomed, and Rutherford had the information in 1910 needed to devise the now accepted theory of electrons orbiting a tiny nucleus. Rutherford developed an equation to describe the scattering if the alpha particles only encountered one large particle. However, while Rutherford's genius devised the theory, Geiger's ability to build the equipment for the experiment demonstrated his talent for invention. Geiger and Marsden spent two more years collecting the data to verify Rutherford's theory.

THE GEIGER-MÜLLER TUBE

A Geiger-Müller tube is a metal tube that is usually about one inch wide and three inches long. There is a metal wire in the middle attached to one end and insulated from the tube. The wire has a voltage (about 1,000 volts) applied to it. The end of the tube, which is not attached to the wire, is a thin film. A gas, usually argon, fills the tube. When a particle such as an alpha particle or a beta particle enters the tube, it ionizes the gas. The electron is attracted to the middle wire and travels very fast to it. As the electron travels to the wire, it causes more ionization, generating a cascade of electrons. The positive ion travels more slowly and is the factor that limits a Geiger counter to a few tens of thousands of particles per minute. When the positive ions reach the shell, they cause electrons to be released. If these electrons are free to cause more ionization, the tube will generate cascade after cascade and be useless. A small amount of a quench gas, which absorbs the secondary electrons, stops the secondary cascade and makes the tube ready to count the next particle. A cascade of electrons can also be generated by a gamma ray or an X ray knocking an electron out of the wall or out of the film of the tube.

A Geiger counter is a Geiger-Müller tube attached to electronics. The electronics detect the voltage difference between the middle wire and the outer shell of the tube. Most Geiger counters have a meter that shows the number of counts per second or minute. Almost all Geiger counters produce an audible click when a particle is detected.

Geiger wanted a better way to detect alpha particles. He built a new detector in 1908 by placing a wire inside a cylinder filled with gas and putting a charge on the wire to make it a cathode and the cylinder an anode. When an alpha particle came through the thin film of the cylinder, it ionized the gas. The ion was attracted to the wire and the electrons to the cylinder, causing an electric spark. Later Geiger adapted the detector so the electric charge difference would enable an electrical circuit to show the number of particles per minute on a meter and would also cause a click. The more alphas entering the tube, the more clicks would occur.

While at Manchester, Geiger did several projects. With Rutherford, he determined the charge on the alpha particles as a plus two by experimentally estimating the total number of alpha particles per second from one gram of radium and the half-life of radium. Geiger and Rutherford also established the basic unit of charge as it exists on particles. In 1908, Geiger proved the statistical character of radioactive decay using his new alpha counter. In 1910, Geiger and colleague J. M. Nuttall found the relationship between the speed of the alpha particles and the half-life of the isotope. This relationship was called the Geiger-Nuttal law. In 1910, Rutherford and Geiger determined that during the decay of uranium, there were two alphas of different energies emitted by the uranium. Geiger then worked with Nuttal in 1912, proving that the two different alphas were produced by two isotopes of uranium.

By 1912, Geiger's fame had earned him the position as director of the new laboratory for radioactivity at the Physikalisch-Technische Reichsanstalt in Berlin. During World War I, Geiger was an artillery officer in the German army. The conditions of trench warfare left Geiger with rheumatism. After the war, Geiger returned to the Reichsanstalt, and in 1920 he married Elisabeth Heffter (1896-1982). His three sons were born in 1921, 1924, and 1927.

At the Reichsanstalt, Geiger adapted his alpha-detecting instrument to detect betas and other types of radiation. He replaced the wire that connected to both ends of the tube with a wire connected to one end. The other end of the wire had a sharp point, so the detector was called a "point counter." One of Geiger's students, James Chadwick, used the new detector to demonstrate that the beta spectrum is continuous. While at the Reichsanstalt, Geiger developed a working relationship with Walther Bothe, and together they developed the coincidence method using two point counters. This method was then used to study the Compton effect, or Compton scattering. Named for Arthur Compton, the theory of the effect is that high-energy electromagnetic radiation increases in wavelength when it collides with electrons. Some scientists concluded that energy was not conserved in these reactions. Only when Geiger and Bothe could detect both the scattered radiation and the recoiling electron could the Compton effect be explained as an outcome of the conservation of energy. This also helped to confirm the quantum theory of atoms.

Geiger became professor of physics at the University of Kiel in 1925. There he worked with Walther Müller to develop the Geiger-Müller tube, which is used to make a Geiger counter. The new counter did not use a sharp point on the wire, and the sensitivity and durability was improved. Geiger discovered that the background noise in his detectors was the detection of cosmic rays. He spent the remainder of his career studying cosmic rays. In 1929, Geiger moved to the University of Tübingen to serve as professor of physics. In 1936, he became head of physics at the Technische Hochschule in Berlin and was named editor for *Zeitschrift für Physik*, a top-quality technical publication. In 1939, Geiger and eight other prominent scientists were called by the army to assess the possibility of an atomic bomb. However, the German nuclear energy project, known as Uranverein (Uranium Club), did not get the support necessary to build a bomb. Whether these scientists would have given a bomb to Adolf Hitler is still debated. By 1940, Geiger's rheumatism kept him in bed much of the time. Shortly after the end of World War II, Geiger's home near Babelsberg was occupied. Although suffering badly, Geiger was forced to flee. He found a place to stay in Potsdam but died within four months.

IMPACT

The Geiger counter is the basic radiation detection instrument. With the Geiger counter, Walther Bothe discovered artificially induced gamma rays in beryllium, and Irène and Frédéric Joliot-Curie used a Geiger counter to discover radioactivity induced by bombardment with other ions. Geiger, however, was more than just the inventor of the radiation detector. He developed the experiments to verify Ernest Rutherford's scattering equation. Without the data that Geiger and Ernest Marsden developed, acceptance of the atomic theory would have been slow. Developing coincidence counting using two or more detectors was another instance in which Geiger designed an experiment to prove a theory, Compton scattering, which kept scientists on the path to truth.

Geiger not only invented instruments and experiments to study nuclear physics but also showed methods to complete the experiments. Geiger was also the first to detect showers of cosmic rays.

—C. Alton Hassell

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See also: Walther Bothe.

IVAN A. GETTING

American scientist

Getting is remembered for his work on the Global Positioning System (GPS), a navigational system that uses satellites to pinpoint the location of a radio receiver. The first operational GPS satellite was launched in 1978, and by 1993 GPS had become fully operational.

Born: January 18, 1912; New York, New York
Died: October 11, 2003; Coronado, California
Also known as: Ivan Alexander Getting (full name)
Primary fields: Aeronautics and aerospace technology; electronics and electrical engineering; military technology and weaponry; navigation
Primary invention: Global Positioning System

EARLY LIFE

Ivan Alexander Getting was born on January 18, 1912, in New York City, the son of Slovak immigrants. His family moved to Pittsburgh, Pennsylvania, where he spent his childhood and first developed an interest in science. Seeking to broaden his scientific knowledge, Getting sought financial assistance to attend college. Upon receiving an Edison scholarship, Getting enrolled in the Massachusetts Institute of Technology (MIT), one of the preeminent scientific institutions in the United States. He received a bachelor of science degree in physics in 1933 and looked for other avenues to extend his education. Upon receipt of a Rhodes Scholarship, he pursued additional training at Oxford University in England. In 1935, he earned a Ph.D. in astrophysics. From 1935 to 1940, Getting worked as a junior fellow at Harvard University researching cosmic rays and nuclear instruments. While there, he designed the high-speed flip-flop circuit that would become a central feature of the first digital computers.

LIFE'S WORK

In 1940, Getting returned to MIT as the director of the Division of Fire Control and Army Radar at the Radiation Laboratory. There he participated in the production of a wide variety of weapons systems that helped secure victory for the Allied Powers in World War II. Getting and his fellow researchers provided the U.S. Army with most of its land-based radars, many of which were technologically advanced. Most notable was the creation of SCR-584, an automatic microwave-tracking gunfire-control radar that proved most effective in intercepting Nazi V-1 bombs, or "buzz bombs," so named for the sound heard right before the projectiles crashed down, that had once wrought terror and devastation on the city of London. It is estimated that Getting's system helped destroy 95 percent of the Nazi projectiles, an achievement that saved thousands of lives and earned Getting the eternal gratitude of the English nation. Getting's efforts also led to the development of the U.S. Navy's GFCS MK-56 antiaircraft fire-control system. During the course of World War II, he also served as a special consultant to Secretary of War Henry Stimson.

Getting's research placed him on the front lines of the Cold War, which developed between the capitalist United States and the communist Soviet Union, owing to intense ideological and geopolitical differences between the two superpowers. The devastating impact of the Nazi invasion on the Russian countryside during World War II prompted Soviet leader Joseph Stalin to seek a buffer between Russia and Germany to protect his country from future attacks. Rather than permit the nations of Eastern Europe liberated by Russian forces to hold free and fair elections, Stalin placed in power communist dictators

THE GLOBAL POSITIONING SYSTEM (GPS)

GPS relies on a network of twenty-four satellites that orbit Earth every twelve hours and continuously emit microwave signals earthward. A GPS receiver picks up signals and calculates the distance between it and the satellites, enabling the user to pinpoint his or her exact location. Designed originally for military use, the system is currently operated by the U.S. Department of Defense under the direct supervision of the Air Force's Fiftieth Space Wing. The U.S. system is the only one of its kind in the world. Two versions of GPS were originally available: one for civilians and the other for the military. The military GPS system, labeled the Precise Positioning System (PPS), was far more accurate than the publicly available Standard Positioning System (SPS). The military encrypted its system but made the less accurate SPS available free to the world. In 2000, President Bill Clinton allowed public access to the more accurate system, helping to boost commercial demand. In times of emergency, the government possesses the ability to return to the selective availability that once marked GPS technology.

In 1991, the U.S. military employed GPS with great success during the Persian Gulf War. During the conflict, the Defense Department held numerous press conferences heralding the accuracy of U.S. weaponry that relied on the GPS system. Military personnel utilize GPS for a variety of purposes, including navigation, tracking, missile guidance, rescue operations, map updating, and management of military bases. GPS usage among civilians continues to expand as new and exciting ways of employing the system are devised.

answerable to him. U.S. officials perceived Stalin's actions as unnecessarily provocative and adopted a hard-line yet patient approach to Russia's expansive tendencies. This policy, called "containment," was intended to check Soviet advances wherever and whenever they might occur. Sometimes containment might take the form of direct military intervention, while on other occasions it might take a more subtle form such as giving financial aid to embattled nations or offering more covert support. New and improved weapons systems were needed to keep perceived American foes in check, and Ivan Getting was one man with the desire and the competence to help.

After World War II, Getting remained at MIT as a professor of electrical engineering and head of the Radar Panel of the Research and Development Board of the Department of Defense. During this period, he helped design and build a 350-million-electronvolt synchrotron. In 1948, he received the U.S. Medal of Merit, but he soon found the life of an academic too limiting. In 1950, he headed to Washington, D.C., to work at the Pentagon for the Air Force before joining the Raytheon Corporation, a civilian defense contractor. As vice president of research and engineering at Raytheon, Getting developed several radar missile systems, including Sparrow III, a semiactive radar-homing air-to-air missile, and HAWK, a medium-range surface-to-air missile. He would later play a pivotal role in the creation of the Polaris, a submarine-launched nuclear surface-to-air missile system. Getting's innovations made Raytheon a top missile provider for both the U.S. government and several of its allies.

In 1960, Getting, along with fellow scientist Bradford Parkinson, created the Aerospace Corporation in El Segundo, California, to further Getting's work in military technology. Under Getting's guidance, the corporation made numerous advances in the production of ballistic missile systems and in the field of space engineering. At Aerospace, he commenced work on his most famous invention—the Global Positioning System (GPS)—which he designed with the assistance of Parkinson. Getting originally conceptualized the system for military purposes only, although he later championed civilian use of GPS. By the mid-1990's, the system was fully functional, with twenty-four orbiting satellites, making the military "smarter" and civilians safer.

Getting's ability to create advanced ballistic missile systems led to work with the National Aeronautics and Space Administration (NASA), where he played a role in the creation of both the Mercury and Gemini programs during the Cold War. Getting's innovations helped the United States keep pace with the Soviet Union in the development of military technology. He is even credited with reinstating the B-1 bomber program, which had been cut by Congress for its extravagant cost. As Getting saw it, prevailing over communism necessitated that the U.S. arsenal include a long-range bomber capable of reaching Soviet territory. When Getting talked, people listened.

Although he retired from Aerospace in 1977, Getting remained an active advocate of GPS and of continued improvements in U.S. military technology. He died in 2003, but his legacy lives on. His work garnered him posthumous induction into the Inventors Hall of Fame in 2004. Getting was the recipient of the Air Force Exceptional Service Award (1960), the IEEE Aerospace and Electronic Systems Pioneer Award (1975), and the Kitty Hawk Award (1975).

IMPACT

Getting fought for years to convince the U.S. government to explore the possibilities of the very expensive Global Positioning System despite repeated efforts by Pentagon officials to stop the program, as they believed that the costs outweighed the potential benefits. Getting's persistence, coupled with mounting evidence of the system's potential utility, eventually bore fruit as the military invested billions in the launching of the satellites necessary to make the system operational. In 1978, the first of the satellites that comprise today's GPS were launched. Thanks to Getting's crusade, today's U.S. military can count on incredible navigational accuracy to keep servicemen and women out of harm's way. Millions of people from all walks of life and various government agencies, including NASA, now utilize GPS technology in cell phones, aircraft, automobiles, and countless other devices and vehicles, ensuring a safe and speedy route to their destinations.

Getting's weapons systems helped the United States and its allies triumph in World War II and helped bring an end to the Cold War. The Soviet Union struggled to keep pace with American advances but soon spent itself into dissolution. Getting played a prominent role in making the United States the world's preeminent military power and foremost producer of military technology.

—*Keith M. Finley*

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See also: John Campbell; Charles Stark Draper; Elmer Ambrose Sperry.

WILLIAM FRANCIS GIAUQUE

Canadian American physical chemist

Giauque won the Nobel Prize in Chemistry in 1949 for his experiments with low-temperature substances, employing a new form of magnetic refrigeration called adiabatic demagnetization. With laboratory machines he helped design, Giauque achieved temperatures within one-tenth of a degree of absolute zero, confirmed the third law of thermodynamics, and discovered the oxygen isotopes of mass 17 and 18.

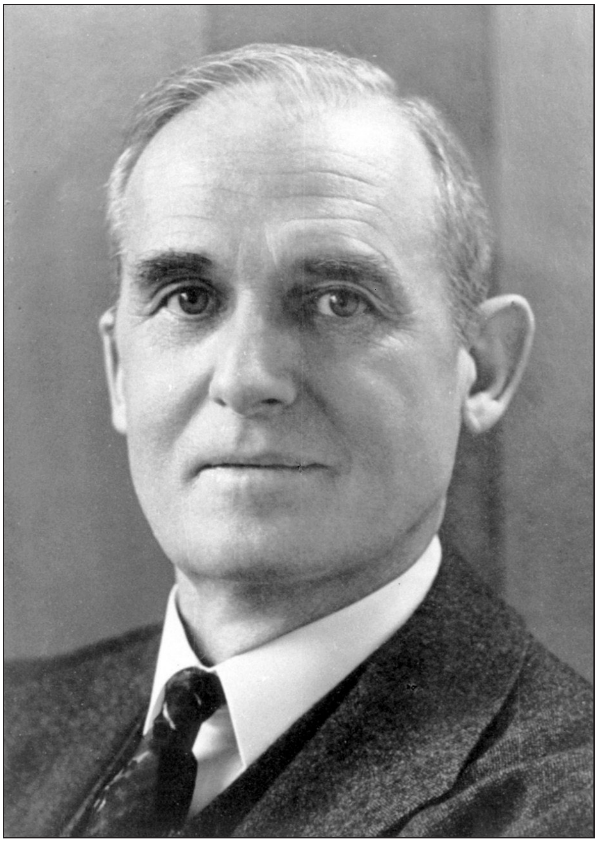
Born: May 12, 1895; Niagara Falls, Ontario, Canada
Died: March 28, 1982; Oakland, California
Primary fields: Chemistry; physics
Primary invention: Adiabatic demagnetization

EARLY LIFE

William Francis Giauque (jee-OHK) was born to William Tecumseh Sherman Giauque and Isabella Jane (Duncan) Giauque in the town of Niagara Falls, Ontario, Canada. William was the oldest of the Giauque's three children. Because their parents were American citizens, William and his younger brother and sister were automatically American citizens as well. While William was still young, his family moved to Michigan, where his father, a skilled carpenter and mechanic, took employment as a weight master and station agent for the Michigan Central Railroad. William attended elementary school in Michigan until his father died in 1908, whereupon the family returned to Niagara Falls, Ontario.

To support the family, Giauque's mother took a job as a part-time seamstress and tailor for Dr. John Woods Beckman, the son of a prominent Swedish parliamentarian and politician, who worked as a chemist for the American Cyanamid Company. Intending to help support the family, Giauque enrolled in the Niagara Falls Collegiate and Vocational Institute. His mother and Beckman persuaded Giauque to switch to the five-year college preparatory course. Graduating in 1913, Giauque worked for two years in the laboratory of the Hooker Electro-Chemical Company in Niagara Falls, New York. It was this laboratory work that sparked Giauque's interest in chemical engineering.

By this time, Beckman had been transferred to Berkeley, California, and he suggested that Giauque continue his studies there. In 1916, Giauque enrolled in the University of California, Berkeley, which had a first-rate chemistry department and low tuition. In 1920, Giauque graduated summa cum laude with a B.S. degree in chemistry. An outstanding student, Giauque stayed on at Berkeley, studying as a university fellow in the 1920-1921 academic year and as a James M. Goewey Fellow in 1921-1922. Giauque also studied the application of quantum statistics to the calculation of thermodynamic quantities, which would prove crucial to his later research. Completing a dissertation on the behavior of matter at low temperatures under the supervision of the eminent chemists George Ernest Gibson and Gilbert N. Lewis, Giauque was awarded a Ph.D. in chemistry in 1922. He was immediately offered a position as an instructor in Berkeley's chemistry department.



William Francis Giauque. (©The Nobel Foundation)

Life's Work

Giauque would remain at the University of California, Berkeley, for the rest of his life, advancing to assistant professor in 1927, associate professor in 1930, and full professor in 1934. He would devote his career to the study of thermodynamics and cryogenics (how matter behaves at low temperatures), for which he would eventually earn a Nobel Prize. On July 19, 1932, he married Muriel Frances Ashley, a physicist and botanist; they had two sons, William Francis Ashley Giauque and Robert David Ashley Giauque.

The basis of Giauque's life work was the study of entropy. Entropy is the state of disorder, or randomness, in a system of molecules. Walther Nernst, a German chemist, had postulated the third law of thermodynamics in 1906. Thermodynamics is the field of chemistry that studies the conversion of heat into energy. According to the third law of thermodynamics, deriving from the Nernst heat theorem, all perfect crystalline substances approach zero entropy as absolute zero temperature is approached. Thus, knowing the heat capacity of a substance at sufficiently low temperatures allows for the calculation of its absolute entropy. As Giauque explained in his December 17, 1949, Nobel lecture, it was the possibility of calculating this absolute entropy that interested him in low-temperature research. In his doctoral dissertation, Giauque had already found support for Nernst's heat theorem with experiments on glycerol gas and crystalline glycerol.

In 1924, Giauque began developing a system of magnetic refrigeration that would allow for achieving the lowest temperatures yet recorded. This process would come to be called adiabatic demagnetization and was based on applying the third law of thermodynamics to the magnetic properties of certain molecules. (An adiabatic system is one in which heat is neither gained nor lost.) The theory of adiabatic demagnetization is complicated; in simple terms, it relies on the fact that certain paramagnetic compounds, such as gadolinium salt, have both thermal and magnetic entropy. At low temperatures, thermal motion disappears, but in these compounds magnetic entropy remains. Their molecules have internal magnetic fields that will line up with an external magnetic field. As the magnetic field is decreased through refrigeration, heat energy of the molecules is transformed into magnetic energy, further lowering the temperature.

Utilizing his adiabatic demagnetization theory, Giauque set out to develop machines in his low-energy laboratory to reach these low temperatures and thus confirm the third law of thermodynamics, that the entropy of a perfect crystal becomes zero at absolute zero temperature. In 1928, Giauque and Henrick Johnston obtained a low temperature of pure hydrogen through their new methods. In 1933, Giauque and his colleagues achieved a temperature of 0.25 kelvin. Another breakthrough came in 1929, when Giauque was focused on entropy calculations of oxygen based on its band spectra. After months of thinking through the problem, Giauque awoke one morning with the sudden illumination that the weak lines in the oxygen spectrum must be due to an isotope species. Giauque and Johnston set about calculating this data, leading to the discovery of isotopes of atomic weights 17 and 18 in the Earth's atmosphere. This discovery proved that molecules retain zero-point vibrational energy at temperatures of absolute zero. It also led to revisions to the atomic weight scales, which would be incorporated in 1961. With the entry of the United States into World War II, Giauque made efforts to assist military research. He developed high-field electromagnets that could be used in military operations. He also directed an effort to build a mobile unit capable of producing liquid oxygen for use in medical operations and for rocket fuel.

Solenoid Magnet with Adiabatic Demagnetization Apparatus

William Francis Giauque and his colleagues in the low-temperature laboratory at the University of California, Berkeley, had to design much of their own equipment to test properties of matter at extremely low temperatures approaching absolute zero. To reach a low enough temperature to measure entropy chemicals is a difficult task. In 1910, Nobel laureate Heike Kamerlingh Onnes had reached temperatures of 0.8 kelvin by evaporating low-temperature helium vapors with a vacuum pump. While taking a graduate seminar in 1924, Giauque presented calculations showing how magnetic fields can affect the thermodynamic properties of various types of matter. Conducting further research, he was surprised to discover that applying a magnetic field to a substance removes a large portion of the remaining entropy, even below the temperatures that Kamerlingh Onnes had been able to reach with his evaporation method. Giauque called this new method adiabatic demagnetization.

Giauque's solenoid magnet with adiabatic demagnetization apparatus was perhaps the crucial piece of laboratory equipment he invented to achieve a low temperature. A solenoid consists of a metal core that is magnetized by a copper coil that is wrapped around the core and that conducts electricity. As a result, the entire metal core becomes a powerful magnet. Giauque placed his adiabatic demagnetization apparatus inside the solenoid magnet. The adiabatic apparatus consists of a copper calorimeter tube containing a sixty-one-gram sample of paramagnetic gadolinium sulphate octahydrate. Helium gas is pumped into a vacuum jacket. The tube and jacket are then placed inside a Dewar flask made of copper lead. The entire apparatus is then placed within the copper coils of the solenoid magnet. The adiabatic demagnetization apparatus is then immersed in liquid helium to a height of one meter. The purpose of the helium gas is to conduct heat. When cooling oil is pumped over the coiled copper conductors, the atoms in the magnet arrange themselves, giving off heat and decreasing entropy. The helium gas is then evacuated from the insulating jacket. Giauque and his team worked on this apparatus for nine years before it was finally ready to be tested.

On March 19, 1933, Giauque and his colleague Duncan MacDougall conducted the first adiabatic demagnetization experiment with the new apparatus. In his 1949 Nobel lecture, Giauque described turning on all the switches as MacDougall sat at a table to record the temperature. Giauque excitedly watched MacDougall's face as he recorded temperatures with their specially designed magnetic thermometer that employed amorphous carbon, which is resistant to electricity. "Cooling has occurred," MacDougall announced. They had achieved a temperature of 0.25 kelvin, a startling improvement on Kamerlingh Onnes's result.

In 1949, Giauque received the Nobel Prize in Chemistry for his research on the behavior of molecules at low temperatures. In the course of his career, he won numerous other prestigious awards, including Columbia University's Charles Frederick Chandler Foundation Medal, the Franklin Institute's Elliott Cresson Medal, the American Chemical Society's Willard Gibbs Medal, and the Gilbert Newton Lewis Medal. In 1941, Giauque and P. F. Meads conducted a fruitful experiment to measure the heat content and entropy of aluminum and copper. Giauque was known as an extremely hard worker who relished his hours teaching students and conducting research in the laboratory. Over his career, he published

183 scientific papers and supervised fifty-one graduate students. He retired in 1981 and died in 1982.

IMPACT

Giauque's contributions in the field of chemistry are numerous. His abiding interest was to bring substances to a state approaching absolute zero temperature, enabling him to study their properties of zero entropy in a relatively stable arrangement without the disorder to which they are normally subject. To accomplish this, Giauque made breakthroughs in the field of adiabatic demagnetization. In a certain sense, Giauque can be seen as following in the footsteps of such electromagnetic pioneers as Michael Faraday and William Sturgeon in conducting research employing solenoids and magnetic fields to test chemical properties. Most of the instruments necessary for such research were created by Giauque and his colleagues in their low-temperature laboratory at Berkeley. As a result of his research, improvements were made in the production of essential and industrial products such as glass, steel, and rubber. His experiments on the movements of molecules at zero entropy allowed for calculations of numerous chemical reactions. For these studies of the properties of matter at near-zero temperatures, he received the Nobel Prize in Chemistry.

Giauque's research confirmed the theoretical work of some of the great theoretical physicists of modern times. Confirming Nernst's third law of thermodynamics, Giauque answered several questions raised by Max Planck. Giauque's study of the spectra of oxygen molecules, leading to the discovery of oxygen isotopes 17 and 18, confirmed Werner Heisenberg's prediction that hydrogen and other elementary diatonic molecules could be in two different states, depending on how their molecular nuclei were oriented. Giauque's low-temperature findings illustrated some of the thermodynamic theories of Lord Kelvin and also led to revisions in the table of standard atomic weights. Giauque's work represents an impressive mix of theoretical and experimental chemistry, his ingenious invention of magnetic instruments allowing for important insights in thermodynamics and atomic physics.

—Howard Bromberg

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See also: Michael Faraday; Heike Kamerlingh Onnes; William Sturgeon.

LILLIAN EVELYN GILBRETH

American engineer and psychologist

Known as the "mother of modern management," Gilbreth was one of the first organizational psychologists and was a pioneer in the field of industrial engineering.

Born: May 24, 1878; Oakland, California
Died: January 2, 1972; Phoenix, Arizona
Also known as: Lillian Evelyn Moller Gilbreth (full name); Lillie Evelyn Moller (birth name); Mother of Modern Management
Primary field: Business management
Primary inventions: Organizational psychology; time and motion study

EARLY LIFE

Lillian Evelyn Gilbreth was born Lillie Evelyn Moller and changed her first name while she was an undergraduate. Her parents were Annie Delger Moller, daughter of a man who became rich selling boots to miners during the California gold rush, and William Moller, a plumbing merchant and scion of a family that had become wealthy in the sugar-refining business. Gilbreth was the second of ten children, although for all practical purposes, she was the oldest because the elder child died as a baby. Despite her father's opposition (he did not approve of women attending college), she attended the University of California, Berkeley, graduating with a bachelor's degree in 1900 and a master's degree in 1902, both in English literature. She wrote her master's thesis on Ben Jonson.

During a 1903 stopover in Boston en route to Europe, Lillian met Frank Gilbreth (1868-1924). He proposed after she returned to the United States, and they were married in 1904. To help Frank with his construction business, Lillian changed her major to psychology. She wrote a Ph.D. dissertation but did not receive the degree from Berkeley because the university refused to waive the residency requirements. Titled "The Psychology of Management," the dissertation was published in thirteen monthly installments in the *Industrial Engineering and Engineering Digest* from 1912 to 1913 and later in book form. She rewrote her dissertation to earn a Ph.D. from Brown University in 1915. It was the first doctorate ever granted in industrial psychology.

Lillian and Frank were the parents of twelve children, eleven of whom lived to adulthood. Their children were Anne, Mary (died of diphtheria in 1912), Ernestine, Martha, Frank Jr., Bill, Lillian, Fred, Dan, Jack, Bob, and Jane. Frank died in 1924, and Lillian never remarried.

LIFE'S WORK

When Lillian met Frank, he was already the owner of one of the largest construction companies in the United States. Her first contribution to his business was indexing a booklet about his company. She then cowrote two

Lillian Evelyn Gilbreth, one of the first industrial psychologists, codeveloped time and motion study to increase workplace efficiency. (AP/Wide World Photos) books with him, *Concrete System* (1908) and *Bricklaying System* (1909), although she did not receive credit.

In 1907, Frank met Frederick W. Taylor, who founded the theory of scientific management. Taylor was a controversial figure at the time, and his system was criticized as being rigid, dehumanizing, and abusive. It consisted of combining financial incentives and training to improve worker productivity after analyzing jobs. The most controversial aspect was his use of a stopwatch. Frank gradually shut down his construction business to become a business consultant using Taylor's methods. He and Lillian formed Gilbreth, Inc., and eventually developed their own variation, which they called motion study, or micromotion study.

MANAGING THE WORKPLACE

Frank and Lillian Gilbreth's first management consulting contract was with the New England Butt Company (NEB), where they installed Frederick W. Taylor's system in 1912-1913. NEB was founded in 1842 and took its name from its first product, butt hinges. In 1855, it started producing braiding machines to produce shoelaces and later electrical insulation. By 1912, the United States was converting to electricity, and there was great demand for such machines. Other products manufactured by NEB included fishing lines, curtain cords, and clotheslines. NEB employed about three hundred people.

Frank was a very gregarious man who could talk to anyone. Workers found him approachable and sympathetic, especially when they found out that he had started as a bricklayer. Lillian was more reserved, so the two divided up the work so that Frank worked at the site while Lillian performed analysis at home. The Gilbreths' major innovation to Taylor's system was to substitute film cameras for stopwatches, and Lillian studied the jobs frame-by-frame to determine the most efficient and fatigue-minimizing methods of performing tasks. Moving pictures were still a novelty at the time, and the workers enjoyed being the stars of the Gilbreths' featurettes. Frank coined the term "therblig," an anagram of "gilbreth," to mean a unit of motion. The basic therbligs were Plan, Search, Find, Select, Grasp, Position, Assemble, Use, Disassemble, Inspect, Transport Loaded, Transport Empty, Wait (unavoidable delay), Wait (avoidable delay), and Rest.

They changed the braider assembly system so that an unskilled laborer would place all the equipment and parts in the proper order on a vertical frame next to the workbench. Frank observed that the skilled workers had to stretch to finish the assembly, so he recommended that the workbench be lowered. Before the Gilbreths restructured the job, it took one skilled worker 37.5 minutes to assemble a braiding machine. Afterward, it took one skilled and one unskilled worker 8.5 minutes.

The Gilbreths also installed more effective cost-accounting procedures, introduced flowcharts, rerouted work procedures, reorganized tool rooms, removed all rolltop desks in favor of flat ones, installed a messenger system and suggestion boxes, and created a planning department. They also introduced an incentive and merit recognition system and the practice of two rest periods a day. Foremen's duties were analyzed and distributed to up to eight different people, including training, repairs, and clerical duties. Other innovations were the installations of clean restrooms, clean lunchrooms, and ergonomically designed chairs. Even the process of cleaning toilets was analyzed. Finally, they installed their home reading box, an open-top box in which employees were encouraged to drop their used magazines and take any that might appeal to them.

Frank and Lillian cowrote *The Primer of Scientific Management* (1911), a textbook of Taylor's system. It is not known how much Lillian contributed, but it appeared solely under Frank's name. Lillian first appeared as a coauthor with Frank with *Fatigue Study* (1916), although she wrote the first draft by herself. Her recommendations for improving productivity by minimizing fatigue included footrests, armrests, adjustable work benches, improved lighting, sensible clothes, and regular rest periods.

During World War I, Frank was commissioned as a major in the U.S. Army, stationed in Oklahoma, and assigned to apply his motion-study techniques to the assembly and disassembly of the Lewis machine gun and other automatic weapons. He made films of the processes and sent them home to Lillian to analyze. After the war, they worked with amputees to develop work techniques that would allow them to rejoin the workforce. Both France and Germany adopted their methods in the rehabilitation of disabled veterans.

Lillian's first project after Frank's untimely death in 1924 was to finish her biography of him, *The Quest for the One Best Way*, which she had hoped to present to him as a birthday present. In 1925, she founded the Motion Study Institute to teach the techniques they had developed. She consulted for Macy's department store from 1925 to 1928 on hiring and training procedures, employee handling, and the organization of clerical work. Specifically, she recommended noise installation and better lighting in the cashier room. In 1928, she worked on personnel policies for Sears, Roebuck and Company and gave lectures at the Denison Company. From 1928 to 1929, she consulted for the Gibbs chain of secretarial colleges. At the same time, she analyzed sandwich preparation for the Green Line chain of restaurants.

Gilbreth's books after her husband's death were *The Home-Maker and Her Job* (1926) and *Living with Our Children* (1928), in which she discussed the challenge of balancing family and career. She recommended taking a scientific approach to homemaker duties so that the woman would have time for a career. She served on President Herbert Hoover's Emergency Committee on Unemployment from 1930 to 1931 and on a subcommittee for the President's Conference on Home Building and Home Ownership in 1930. She also served on committees for Presidents Theodore Roosevelt, Harry S. Truman, John F. Kennedy, and Lyndon B. Johnson. She served as a member of the board of directors of the Girl Scouts from 1930 to 1950.

In 1934, Gilbreth designed three of the rooms in "America's Little House," a three-bedroom model home built by the Better Homes in America. They were the kitchen, the clothing closet, and the nursery. She then became a consultant for General Electric in its designs for washing machines and refrigerators. She helped the *New York Herald Tribune* set up its Home Institute and consulted for New York University Medical Center's Institute of Rehabilitation Medicine on how to design a kitchen for the handicapped. During World War II, she consulted for manufacturers hiring women assembly workers for the first time. Gilbreth taught management at the School of Mechanical Engineering at Purdue University from 1935 to 1948. She later taught at the Newark College of Engineering, the University of Wisconsin, and the University of the Philippines.

IMPACT

Gilbreth was famous during her lifetime for being able to balance career and family. She did have one advantage that most twenty-first century women do not, however: Her mother-in-law lived with the family until her death in 1920 and served as the household manager. Then, the eldest child still living at home took a turn at managing the house. In addition, Gilbreth always had servants. Even during the time of the family's lowest income for a few years following Frank's death, she employed a handyman who doubled as a cook. Nonetheless, bearing and raising twelve children is extremely time-consuming. All eleven who survived to adulthood graduated from college and raised families of their own. Gilbreth was also a model for senior citizens in that she maintained her heavy lecturing and teaching schedule until the age of ninety.

Her contribution to the scientific management movement was the application of educational psychology to the movement's techniques. Her study of fatigue in the workplace eventually became known as ergonomics. Much of her work involved the handicapped, and she worked with the American Institute of Architects to provide wheelchair accessibility in existing buildings and to incorporate wheelchair-friendly restrooms, elevators, and ramps into the standards for new buildings.

In 1965, Gilbreth became the first female member of the National Academy of Engineering. In 1954, the Western Society of Engineers gave her its Washington Award, and in 1966 the American Society of Civil Engineers gave her the Hoover Medal. In 1962, the American Institute of Industrial Engineers devoted its annual conference to the work of the Gilbreths. She was named Outstanding Alumnus by the University of California, Berkeley, in 1954.

—*Thomas R. Feller*

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See also: Josephine Garis Cochran; Jay Wright Forrester.

KING CAMP GILLETTE

American businessman

The inventor of the first safety razor using a disposable blade, Gillette transformed the practice of shaving, developed an innovative business model still in use over a century later, and became a pioneer in the manufacture and sale of disposable products.

Born: January 5, 1855; Fond du Lac, Wisconsin
Died: July 9, 1932; Los Angeles, California
Primary field: Household products
Primary invention: Safety razor

King Camp Gillette. (Library of Congress)

EARLY LIFE

King Camp Gillette (jih-LEHT) was the youngest of three sons born to George Wolcott Gillette, a newspaper editor, and Fanny Lemira Camp Gillette, who would later attain fame as the author of a best-selling cookbook. Born in rural Wisconsin, Gillette spent his formative years in Chicago, Illinois, where his family moved when he was very young. His father reportedly instilled in Gillette an interest in mechanics, his mother an emphasis upon efficiency and effective time management. In 1871, when Gillette was seventeen, the great Chicago fire destroyed his family's home and possessions. When the elder Gillette subsequently moved his family to New York, King Gillette remained in Chicago, where he worked as a clerk for a hardware company.

As a young adult, Gillette held a series of jobs, primarily as a traveling salesman. In his spare time, he experimented with various inventions, but he failed to create a marketable product. By the time he married in 1890, Gillette had achieved a measure of success and financial security, yet over time he had grown increasingly dissatisfied with contemporary society and had begun exploring socialist ideas and writings. In 1894, Gillette published *The Human Drift*, which outlined his vision of a utopian society and criticized free market capitalism, which he claimed was the cause of poverty, crime, and other social ills.

LIFE'S WORK

In the early 1890's, while working as a salesman for the Baltimore Seal Company, Gillette developed a friendship with the company president, William Painter, who had recently developed a metal bottle cap that would become the standard for the bottling industry. Painter encouraged Gillette to invent a disposable product that consumers would use regularly and for which there would thus be a constant demand.

Gillette conceived such a product in 1895 while shaving on a moving railroad car using a straight razor, which required considerable skill to use under the most favorable circumstances as well as a great deal of sharpening and maintenance. Gillette envisioned a razor that would use interchangeable blades that never required sharpening and could employ guards to reduce the risk of injury to the user. Gillette began experimenting with various prototypes of razors and blades but quickly encountered difficulty fashioning blades that were thin enough to be cost-effective and sufficiently strong to withstand the rigors of shaving. He struggled with developing a successful prototype until around 1900, when he collaborated with William Nickerson, a mechanical engineer known for his skill in bringing ideas for inventions to fruition. Gillette and Nickerson became partners, forming the Gillette Safety Razor Company, so named because Gillette believed that including "Nickerson" in the company name would remind consumers of the nicked skin that often accompanied shaving.

Although other safety razors had been developed and marketed by the time Gillette introduced his razor to the public, the Gillette safety razor was the first to feature disposable blades. The use of these blades completely eliminated the tedious process of sharpening in addition to greatly reducing the risk of serious cuts. The company began mass-producing razors and blades in 1903, selling only 51 razors and 168 blades. The following year, sales of the product exploded as the company produced 90,000 razors and over 12 million blades.

In the process of marketing his safety razor, Gillette introduced a new business strategy that would be copied by countless other future entrepreneurs. In order to create a market for his disposable razor blades, Gillette marketed his safety razors at a very low cost. Those who purchased the razors and grew accustomed to using them had no choice but to purchase replacement blades, which would produce both short-term and long-term profits for the company. Gillette razors thus became an early example of a loss leader, an item offered for sale at or below cost in order to generate sales of another, often related item. This strategy later became known as the razor-and-blade model.

THE SAFETY RAZOR

Prior to the invention of the safety razor, shaving was a time-consuming act involving a straight razor, which had to be sharpened constantly to ensure its safety and effectiveness. Straight razors, often called "cut-throat razors," were hazardous devices that were frequently used as weapons. Even the most skilled users could not avoid the occasional nick or cut, and occasionally infections contracted from shaving cuts resulted in serious illness or even death. Other methods of hair removal, such as plucking or depilatory chemicals, were often used in place of shaving, particularly by women.

The possibility of developing a safety razor was realized as early as the late 1700's. In 1880, the Kampfe brothers developed a successful safety razor that utilized a wire blade guard to protect the user, but the blade was not disposable and required frequent removal and sharpening; thus, the device never achieved widespread popularity. By combining the element of safety with the convenience and efficiency of a disposable blade, King Camp Gillette invented the first successful safety razor.

The initial design for the Gillette razor was simple: a thin metallic blade sandwiched between two metal plates and attached to a handle. The razor covered all but a fraction of the blade, preventing deep cuts and reducing the frequency of small ones. This design was essentially complete by 1895; but the development of a component sufficiently thin, durable, and inexpensive to serve as a disposable blade is credited to Gillette's partner, William Nickerson, who had developed a viable blade by 1903. Gillette applied for a patent for his safety razor in 1901, and was awarded a patent in 1904.

The Gillette razor greatly reduced the amount of time required to shave, due primarily to the elimination of the sharpening process and the exacting technique required of straight-razor users. Some users of the Gillette razor reported that it cut their shaving time by two-thirds to three-quarters. The reduced risk of shaving with a safety razor also contributed to its popularity, particularly among women. Although other companies introduced their own versions of the safety razor during the early twentieth century, Gillette would continue to dominate the market into the latter half of the century, introducing stainless-steel blades in the 1960's.

Although replacement blades for safety razors were still available to consumers in the early twenty-first century, use of the razors declined steadily after introduction of the plastic disposable razor in the 1960's. Several manufacturers, including Gillette, subsequently produced a variety of styles of disposable razors, from inexpensive single-blade models to multibladed shavers with pivoting heads, lubricating strips, and other features.

Gillette officially retired from day-to-day operation of his company in 1913. Although he would continue as company president, Gillette devoted much of his later years to political writings and activism. Meanwhile, the company that he cofounded continued to expand as its product became increasingly popular in the United States and in overseas markets. A Gillette razor designed specifically for women was introduced in 1916 and became an immediate success. Gillette initially resisted the sale of overseas rights to Gillette products, but he relented after U.S. soldiers involved in World War I introduced Gillette razors to Europeans. Gillette had entered into an agreement with the U.S. government in 1917 to provide Gillette shaving products to American soldiers, just as the U.S. military was expanding in preparation to enter the war. Gillette would supply approximately 3.5 million razors and 36 million blades to American troops, expanding its customer base dramatically and ensuring continued demand for disposable blades.

The success of his company provided Gillette with the financial security to pursue his passion for political reform. Unlike many proponents of socialism, Gillette thought that a utopian society could best be achieved through the development of monopolies, the culmination of which, he reasoned, would be the creation of a single global corporation that would employ all workers and produce all goods and services and in which each citizen of the world would hold stock and receive dividends. This corporation, Gillette reasoned, would pay sufficient dividends to allow each citizen to work only five years before retiring. Gillette also proposed the construction of a utopian city near Niagara Falls, New York, in which millions of people would reside in communal apartment complexes and share labor and resources. Utilizing his influence as a successful entrepreneur, Gillette published a series of political and economic treatises during the early twentieth century. Gillette was able to secure the assistance of several prominent individuals to disseminate his ideas, such as authors Sinclair Lewis and Upton Sinclair, and fellow industrialist Henry Ford.

Gillette spent his final years in Los Angeles, where he continued to write and to serve as president of the Gillette Company until 1931, when he resigned his position because of ill health. Poor investments and the expense of publishing his political writings claimed a large portion of his vast fortune in the 1920's, and the stock market crash of 1929 resulted in more financial losses for Gillette. He died on July 9, 1932, at his home, with his wife and son in attendance.

IMPACT

While none of his social and political ideas were realized, Gillette exerted a dramatic influence upon society through the creation of his safety razor and the disposable blades that accompanied it. Simplifying the task of shaving led to a transformation of American fashion, as the beards, muttonchop sideburns, and "soup-strainer" moustaches popular among men of the late nineteenth century slowly disappeared to be replaced by a more clean-shaven look. Shaving also became increasingly popular with women, instigating fashion trends emphasizing shorter skirts, sleeveless dresses, and smaller bathing suits. By the 1940's, advertisements touting the hygienic and aesthetic benefits of shaving legs and underarms frequently appeared in publications targeting women.

As one of the first disposable consumer products, the Gillette razor blade set a precedent for the marketing and use of goods intended for short-term use and frequent replacement. As a result, Gillette has been both praised as a pioneer of modern convenience and criticized as an architect of a culture of waste and superficiality. His reputation as a business innovator was enhanced by his creation of the razor-and-blade business strategy, which remained in use into the twenty-first century.

—Michael H. Burchett

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See also: Henry Ford; Jacob Schick; Paul Winchell.

CHARLES P. GINSBURG

American electrical engineer

Ginsburg led the team that developed the first practical videotape recorder, a device that completely revolutionized the television industry. The ability to record on videotape allowed television studios to record shows to be broadcast at later times, to present instant replays of events, and to have permanent copies of programs.

Born: July 27, 1920; San Francisco, California
Died: April 9, 1992; Eugene, Oregon
Also known as: Charles Paulson Ginsburg (full name)
Primary field: Electronics and electrical engineering
Primary invention: Videotape recorder

EARLY LIFE

Charles Paulson Ginsburg was born in San Francisco on July 27, 1920. He was diagnosed with diabetes when he was four years old, and, even with insulin treatment, he had to learn what and when he needed to eat to maintain a healthy sugar level. He never cheated on his diet, but owing to the effects of diabetes, Ginsburg had to have a leg amputated when he was in his forties, and his eyesight deteriorated in his later years.

Ginsburg grew up and went to school in San Francisco. In return for his father's medical services (Ginsburg's father was a radiologist), Ginsburg and his sister received golf lessons from a professional; golf remained a passion for Ginsburg throughout his life. After high school, Ginsburg chose to enter the University of California at Berkeley, with the intention of pursuing medicine. Later he decided to change to the University of California at Davis to study agriculture and animal medicine. He was not able to finish college, however, because of a lack of funds; his father's failing health had led to the loss of his medical practice, and the family had no money for Ginsburg's education.

Ginsburg went to work for a service that set up sound equipment for public events. His next job was installing telephones, and after that he worked on the transmitters for a radio station. These jobs sparked Ginsburg's interest in engineering, and he began to take courses in electrical engineering and then in physics. His laboratory classes in physics interfered with his work hours (he was working forty-eight hours a week at the radio station), so he switched to mathematics and transferred from the University of California to San Jose State College, where he also took several engineering courses. He received his bachelor's degree in math in 1948, when he was in his late twenties. After graduation, he continued to work for radio stations in the San Francisco area.

LIFE'S WORK

In 1951, television was making a name for itself. Throughout the United States, people were beginning to turn off their radios and purchase television sets. World, regional, and local news as well as entertainment and sports were being broadcast from stations all over the nation. Television had a few drawbacks, however, including the fact that all programming had to be live or filmed. Recording programs on film was time-consuming, and the filmed footage was expensive to develop and edit. Many shows were thus presented live rather than recorded. This meant that there was no way to delay broadcast of a program by one or two hours, or to show any action in slow motion, or to replay a scene within a short time period.

Alexander M. Poniatoff, founder and president of Ampex Corporation, and his top technical aides decided to set in motion a secret project to build a videotape recording machine. They had heard about Ginsburg and his work and were impressed with Ginsburg's solid background in mathematics. They offered him the job of directing the research on a videotape recorder in early 1952. Later that year, the project was suspended for three months for another project. During the suspension, Ginsburg met a young college student, Ray Milton Dolby, whose name later became associated with stereo sound systems. Ginsburg and Dolby went back to work on the video recorder, and by October of 1952 they demonstrated a system that could replay a scene from tape. The picture was not good, but it was enough to indicate progress and push the project forward.

The original idea had been to create a machine that

Videotape Recorder

A television camera divides a picture into a large number of small segments, or pixels. The camera records the intensity and brightness of each pixel, and that information is then translated into binary code, which can be stored on magnetic tape. Such tape consists of a plastic backing covered by a thin gel containing iron oxide particles. The tape recorder has to rearrange the iron particles so that later a scanner can read the arrangement of the iron particles and re-form the binary code, which can be translated back into intensity and brightness of each pixel on a monitor. The recorder has to convert the sound into binary code and onto the magnetic tape as well. The first attempts to use magnetic tape to record video used a system similar to an audio recorder. In order to record video, with its high frequency, onto magnetic tape, the tape had to be moving at about 240 inches per second. This high speed often pushed the recorders beyond their capability.

The first practical video recorder, developed by Charles P. Ginsburg and his Ampex research group, ran the tape at a much slower speed by using rotating heads to arrange the iron oxide particles. The tape was two inches wide, with a narrow track on one side for the audio signal, a narrow track on the other side for a cue signal, and a wide track in the middle for the video signal. The tape was held in place by a vacuum system. An audio recorder put on the audio signal, a cue recorder put on the cue track, and a video recording head put on the video signal in parallel lines across the tape. Each line contained the information for the pixels of one-sixteenth of the picture.

The video recording heads built by Ginsburg's group were the first such heads to be composed of a ferrite core with metal tips. The group redesigned the heads so that they had a sandwich structure. These new heads were easier to manufacture than were previously used heads and could be made to work at lower wavelengths. The heads, which were inside a drum around which the tape wrapped, rotated at a fast speed so that the tape did not have to move so fast. The heads arranged the iron oxide particles with a magnetic field. In front of the heads were degaussing heads to make sure that no leftover iron oxide arrangement remained on the tape. Ginsburg and his group found that reducing the tension on the tape was another change that needed to be made. The result of the group's work was a videotape recording system that allowed users to record on videotape, edit the recorded material, and replay the material on demand.

would use fast-moving tape passing by three heads, but Ginsburg and Dolby decided that such a system was not workable. Their new system, which had four heads mounted on a rotating drum, produced a better picture but had enough problems to warrant a new design. The project was again suspended from June, 1953, to August, 1954, but Ginsburg and Dolby continued to work on their system. They solved enough problems that the project was restarted with a new design and several new group members, including individuals who would later be involved in the development of the home videotape recorder. The group moved into a more spacious work area and ran experiments on every part of the equipment. The automatic gain control was changed to an FM (frequency modulation) system. The tape wrapped around the drum, and the recorded information was written in lines across the tape.

By early February of 1956, the system was ready to show to the Ampex board of directors. First a short segment that had been recorded earlier was shown, and then the system was used to record the assembled Ampex people as they watched the process. After two minutes of recording, the machine was stopped and the tape was rewound. The recorded two minutes were then played for the group. When the tape finished, there was silence, then huge applause. Ginsburg had led his group to build a machine that could record from a television camera onto tape and then could replay that tape almost immediately. A surprise showing was scheduled right away for the meeting of the affiliates of the Columbia Broadcasting System (CBS), and a day later the system was displayed at the national meeting of the National Association of Radio and Television Broadcasters. The demonstrations were hugely successful, and orders for the new recorder soon began to come in from television stations across the nation.

Ginsburg's work was not done, however. Working out the last of the system's problems and preparing for the manufacture of many units required a lot of time and effort. On November 30, 1956, videotape was used in a broadcast for the first time when CBS presented a delayed broadcast of *Douglas Edwards and the News*. By April, 1957, the American Broadcasting Company (ABC) and the National Broadcasting Company (NBC) were also broadcasting delayed programs using videotape.

Ginsburg continued to work on the system, helping to develop stop-action and slow-motion features. He also helped to develop color recording on videotape and, later, the videocassette recorder (VCR). Ginsburg was awarded seven U.S. patients and thirty-two foreign patents. Never one to be concerned about whose idea was used or who got credit, Ginsburg was the glue that held the group together. He knew how to encourage, when to try to help, and how to divide the work among members of the team. Ginsburg retired in 1986; he died at his home in Eugene, Oregon, on April 9, 1992.

IMPACT

The videotape recorder completely revolutionized television. Shows no longer had to be broadcast live—they could be taped, edited, and broadcast at convenient times. By using videotape, American television networks could easily address the problem of programming for the different time zones across the United States. Videotape also meant that individual programs could be saved for archiving and rebroadcast. Before videotape recording was possible, many television programs as well as televised concerts, sporting events, and news events were not recorded by any method. Videotape recorders were also quickly put to use recording events in many places where human beings could not safely go, such as caves, volcanos, and outer space.

The bulky video recording system that Ginsburg and his group originally designed was later refined and reduced to produce the home video recorder. With the VCR, individuals could record their favorite shows for later viewing and to keep for repeat viewing. In addition, when film studios began making motion pictures available on videotape for sale or rental, they created a new industry and expanded the filmmaking industry.

—C. Alton Hassell

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See also: Marvin Camras; Vladimir Zworykin.

DONALD A. GLASER

American physicist

Glaser's development of the bubble chamber, a device for the study of atomic particles, won him the 1960 Nobel Prize in Physics. His later work in molecular biology led him to found Cetus Corporation, a pioneering biotechnology company.

Born: September 21, 1926; Cleveland, Ohio
Also known as: Donald Arthur Glaser (full name)
Primary field: Physics
Primary invention: Bubble chamber

EARLY LIFE

Donald Arthur Glaser was born in Cleveland, Ohio, on September 21, 1926. His parents, William and Lena Glaser, had emigrated to the United States from Russia. William operated a wholesale merchandising business in Cleveland, and Donald attended elementary and high school there. As a child, Glaser took violin lessons and attended music composition classes at the Cleveland Institute of Music. Showing an early talent for music, he became a member of a local symphony orchestra while still in high school. Science, however, proved his keenest interest, and Glaser remained in Cleveland for his undergraduate education, entering Case Institute of Technology (now Case Western Reserve University) to study mathematics and physics. He completed his graduate course work at the California Institute of Technology and received his Ph.D. in physics in 1950, a year after he accepted a position as instructor at the University of Michigan in Ann Arbor, Michigan. Glaser's academic adviser was Nobel laureate Carl Anderson. Glaser was made full professor there in 1957 at the age of thirty-one, and he remained at Michigan until 1959.

According to legend, Glaser first conceived of his most famous invention, the bubble chamber, in 1952, as a young faculty member at the University of Michigan. According to a widely told story, Glaser was enjoying a cold beer when he observed the stream of bubbles in his brew. The movement of the bubbles inspired him to create a superheated, liquid-filled chamber in which atomic particles could be tracked by the bubbles they left behind. The story has the charm of a true "Eureka!" moment; however, Glaser refuted it in a July, 2006, lecture at the University of California, Berkeley, as reported in the *Berkeley Lab View*. While he said that beer did not inspire his concept for the bubble chamber, Glaser did experiment with using beer as the liquid. The results were unsatisfactory, not to mention odoriferous, and he ultimately used liquid hydrogen. Glaser described his initial experiments with the bubble chamber in a 1952 article published in the *Physical Review*, "Some Effects of Ionizing Radiation on the Formation of Bubbles in Liquids."

LIFE'S WORK

Shortly after earning his doctorate, Glaser had applied to the University of California, Berkeley. He was told that no faculty positions were available. In 1959, after consulting during the summers at the Lawrence Radiation Laboratory in Berkeley, Glaser joined the University of California faculty. One year later, he received the Nobel Prize.

Berkeley in the 1950's and 1960's was an exciting place for physics research. The physics program at the university had been home to such prominent scientists as Ernest Orlando Lawrence, inventor of the cyclotron (a device used in atomic research), and J. Robert Oppenheimer, one of the architects of the atomic bomb. The Lawrence Berkeley National Laboratory, where Glaser would do his research, was home to no less than nine Nobel laureates. It was the ideal environment for Glaser to perfect his bubble chamber and extend his research.

Glaser's first prototype bubble chamber was a thumb-sized glass bulb, but later models were much larger. Glaser's xenon bubble chamber was nearly the size of a small bus. The principle remained the same, however: Heated liquid is used to trace the motion of atomic particles invisible to the naked eye or even a microscope. As the charged particles pass through the liquid, energy is released, triggering enough bubbling to leave a visible trail. The trails of bubbles can be photographed, allowing scientists to study the particles.

The bubble chamber was an improvement on an earlier invention, the cloud chamber, which Glaser had used during graduate study. Cloud chambers used cooled vapor to track the movement of particles, but they were not sensitive enough to capture the high-energy particles Glaser wanted to study. Through a series of experiments using the bubble chamber, Glaser was able to gain information on the mass, life cycles, and decay mode of several newly discovered particles.

Glaser was awarded the Nobel Prize in Physics in November, 1960. Another Berkeley professor was awarded the prize in chemistry. It was the first time that two scientists from the same university won Nobel Prizes in the same year. The year 1960 was also significant in Glaser's personal life: He married Ruth Bonnie Thompson. They had two children, but later divorced. Glaser married again in 1975, to Lynn Bercovitz, a painter. Glaser retained his interest in music and also enjoyed outdoor activities such as hiking, sailing, kayaking, and scuba diving.

Glaser's work with the bubble chamber was later expanded upon by Berkeley physicist Luis W. Álvarez, who was in turn awarded the Nobel Prize in 1968. Glaser, meanwhile, had moved from physics to explore a new field, molecular biology. One study Glaser conducted showed that mutations in cultivated hamster ovary cells caused abnormal sensitivity to ultraviolet light, which could cause the cells to become cancerous. Glaser found a connection to defective genes in humans associated with the disease xeroderma pigmentosum, in which any exposure to daylight can trigger cancer. It became clear that genetic research could be the key to treating, preventing, or even eradicating many human diseases.

In 1971, Glaser and two friends, Peter Farley and Ronald E. Cape, founded Cetus Corporation, one of the first biotechnology companies. One of Glaser's motivations, he told writer Stuart Gannes in *Fortune* magazine in 1987, was to conduct research that not only was theoretical but also would have a useful social benefit. Cancer treatment seemed a most pressing need since, as he explained, everyone knows someone who has died of cancer. Although Glaser was Cetus's largest shareholder, he never went to work for the company full-time but instead remained a professor at Berkeley. He told *Fortune* that he enjoyed the intellectual freedom he found in academia, the ability to move from one field of science to another.

During the 1980's, Cetus was involved in DNA testing and research and in the production of beta-interferon and interleukin-2, anticancer drugs that targeted the immune system. Beta-interferon was later modified to treat multiple sclerosis. While interleukin-2 showed promise in early trials, it also had significant side effects that delayed its approval. The delays caused financial problems that eventually led to Cetus's being sold in 1991.

Meanwhile, Glaser had turned to another scientific interest, neurobiology. Since the early 1990's, he has been professor of the Graduate School Division of Neurobiology at Berkeley, where his research focus is the human visual system. Glaser has also served as consultant and adviser to governmental organizations, nonprofit groups, and scientific publications.

IMPACT

Glaser's bubble chamber allowed scientists to observe particles far too small for the human eye to see. For more than thirty years, the bubble chamber was essential to the study of particle physics. Frustrated by the limitations of the cloud chamber, which was not sensitive enough to capture the smallest particles, Glaser improvised and made a historic discovery that allowed scientists to study the smallest units of energy that make up the universe. His first bubble chamber, a simple glass tube small enough to be held in its inventor's hand, worked in essentially the same way as later, more advanced models by using a clear, heated liquid through which atomic particles moved. By observing the trails of bubbles left behind, Glaser and other physicists were able to learn about the structure and behavior of these particles. For example, neutrinos, elementary particles generated by solar radiation or nuclear reaction, travel at speeds close to the speed of light and are so minuscule that they were undetectable until the advent of the bubble chamber.

In Glaser's 1960 Nobel Prize acceptance speech, he acknowledged that the field of high-energy nuclear physics, which deals with experiments on particles too small to perceive directly, must seem remote from the world of everyday life. Yet such experiments have brought humanity closer to understanding the primal forces that shape not only the world and its origins, but the greater universe and perhaps even the origins of all life.

—*Kathryn Kulpa*

THE BUBBLE CHAMBER

Although he has made significant contributions to molecular biology and neurobiology, Donald A. Glaser is still best known as the inventor of the bubble chamber. Although he may not have been inspired by watching bubbles in a glass of beer, as legend has it, Glaser certainly made an inspired choice when he decided to try using heated liquids to track the movements of atomic particles. Glaser built his first working bubble chamber in 1952 and reported on his experiments in the *Physical Review*.

Just as Glaser had built upon the work of other physicists before him, particularly Charles Wilson's cloud chamber and Cecil Powell's work in nuclear emulsion, Glaser's work inspired others in the same field. The scientific community recognized the significance of Glaser's discovery, and soon physicists around the world were working with Glaser's ideas. A study published in 1957 was cosigned by Glaser's research team at the University of Michigan, researchers from Columbia University, and two other research teams from Bologna and Pisa, Italy. In his Nobel Prize acceptance speech, Glaser emphasized the importance of collaboration and cooperation among scientists.

Over the years, bubble chambers grew larger and more sophisticated, but their basic operation remained essentially the same. A liquid, such as diethyl ether or, more often, liquid hydrogen or a mixture of hydrogen and neon, is subjected to changes in atmospheric pressure, causing it to become superheated. Accelerated atomic particles move through the liquid, and their energy ionizes atoms, causing boiling and creating a trail of bubbles. The bubbles are allowed to grow to a diameter of about one millimeter, at which point they can be seen through the window of the chamber and even captured with high-speed photography.

Glaser's bubble chamber enabled researchers to discover new subatomic resonance particles. By studying the trails of bubbles particles left behind, physicists were able to gain knowledge of atomic particles in action: their mass, lifetime, interaction with one another, and mode of decay. Bubble chambers have also been used to study weakly interacting massive particles (WIMPS) and neutrinos (minuscule elementary particles). Such studies may seem esoteric, but they are essential to new research in particle physics and quantum mechanics focusing on the existence of dark matter, a still-mysterious substance thought to make up the bulk of the known universe.

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See also: Luis W. Álvarez; Walther Bothe; Ernest Orlando Lawrence; J. Robert Oppenheimer; Edward Teller.

JOSEPH GLIDDEN

American farmer

Glidden created a convenient fencing system for farmers and ranchers known as barbed wire and a machine to twist it into place. His invention changed the face of the American West by encouraging farming and ranching in enclosed parcels of land and had long-term implications for use in war and imprisonment.

Born: January 18, 1813; Charlestown, New Hampshire
Died: October 9, 1906; De Kalb County, Illinois
Also known as: Joseph Farwell Glidden (full name)
Primary field: Agriculture
Primary invention: Barbed wire

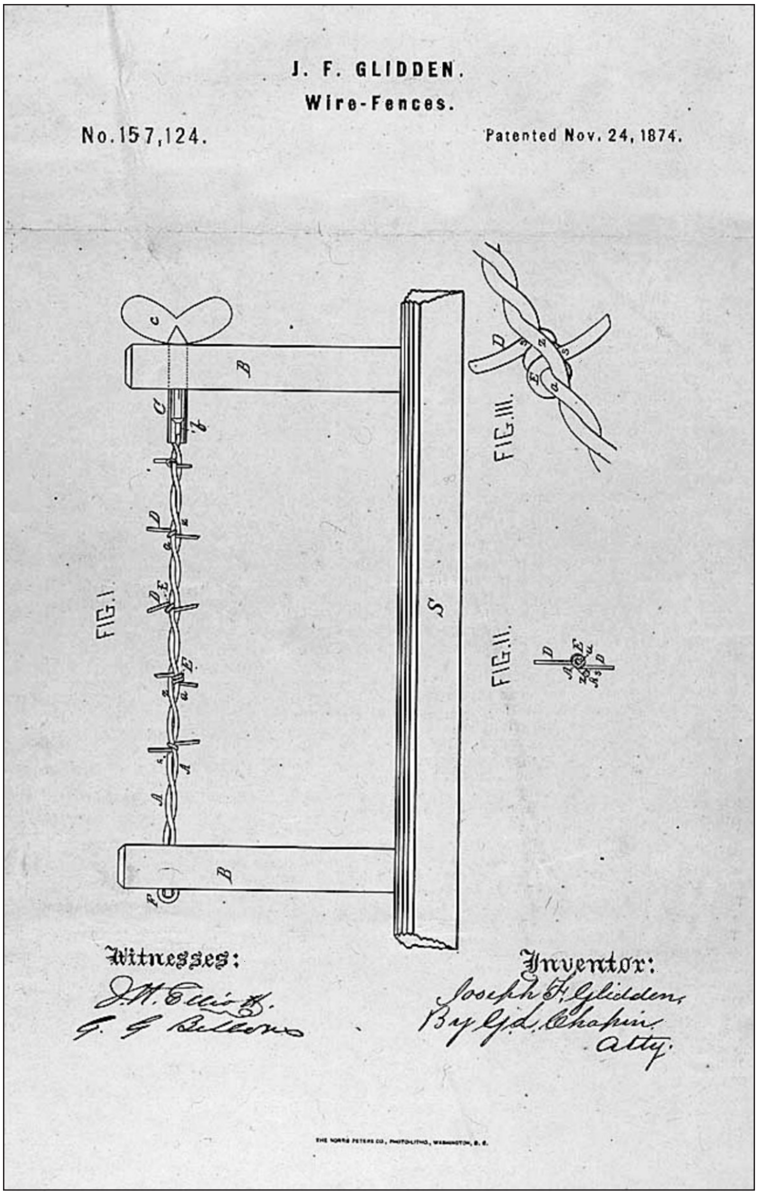
EARLY LIFE

Joseph Farwell Glidden was born on January 18, 1813, on a farm in Charlestown, New Hampshire. His parents, David and Polly Glidden, moved to Clarendon, New York, where he attended school. Joseph later studied at the seminary in Lima, New York. In 1837, he married Clarissa Foster. He taught school and threshed grain to support his young family, and in 1842 he purchased a six-hundred-acre farm in De Kalb County, Illinois. Glidden and Clarissa had three children, two boys and a girl, but Clarissa died after giving birth to their daughter. All three children died shortly after they settled in Illinois. In 1851, Glidden married Lucinda Warne. The couple had one daughter, Elva, his only surviving child. Lucinda was rumored to have helped Joseph invent barbed wire.

LIFE'S WORK

For centuries, farmers used fencing to delineate the boundaries of their land and to protect their crops. Fences held livestock and protected them from predatory animals and thieves who might hurt or steal them. Historically, fences were constructed of wood, hedges, and stone. Early American farmers in the East relied mostly on wooden fences to enclose their farms and properties, and western settlers followed suit. However, when settlers faced the challenges of the Great Plains, agricultural technology failed them. In addition to the extreme weather, the lack of water, and the difficulty of cutting through thick prairie sod with iron plows, there was a significant lack of trees. Previous settlers relied heavily on wood to build and heat their homes, cook their meals, and fence in their lands. Without this valuable resource, settlers avoided the Great Plains for decades, and the area gained the nickname the "Great American Desert."

In 1862, Congress passed the Homestead Act to encourage western settlement by promising free land to those who worked the property for five years. The invention of the steel plow in 1837 had made cultivating the tough prairie sod easier. Homes were constructed of sod, and twisted prairie grasses and buffalo chips provided fuel for fires, but a low-cost, convenient fencing system was still lacking. Wood could be shipped west by train, but it was expensive to do so. Farmers experimented with wire, but the fences were easily pushed down by the livestock they were trying to contain.



Patent drawing for Joseph Glidden's barbed wire. (NARA)

As a farmer for most of his life, Glidden faced the same problems as others of his day. In 1873, he attended a county fair where a wooden fencing system with nail-like projections was displayed. The nail-like projections inspired him to create his own fencing. At his farmhouse, Glidden used a coffee grinder to create barbs, which he then placed on a strand of wire. He locked the barbs in place by wrapping another strand of wire around the barbed one. He strung the barbed wire on his farm along a roadway where neighbors saw it and requested some of the same material. Soon he was in business. On October 27, 1873, Glidden applied for a patent for his improved fencing system; a year later, he filed a patent application for a machine to twist the wire into place. Within days of his first application, challenges were asserted by others who maintained prior claim to the invention, delaying the patent process. Two other men had attended the same fair Glidden attended and professed to the same inspiration. Additionally, previous patents had been granted for similar wire fencing systems. Nevertheless, Glidden's invention, "Improvement in Wire-Fences," was granted U.S. Patent number 157,124 on November 24, 1874. Still, court battles continued for almost twenty years until the U.S. Supreme Court decided in Glidden's favor in 1892.

In the meantime, Glidden tried to keep up with the business orders he received. He joined local hardware store owner Isaac Ellwood to form the Barb Fence Company. Early on, the Barb Fence Company purchased patent rights from some of its competitors. Glidden and Ellwood built a small factory and marketed to farmers throughout the nation. Various methods were employed to spread the word about the new invention, including articles in newspapers, periodicals, and billboards as well as presentations at county fairs. The numerous court cases, though trying, brought valuable publicity to the new product. The company hired traveling salesmen to market in outlying areas with great success. Easy to travel with, and impressive in its simplistic yet practical nature, barbed wire was an easy sell. In 1876, Glidden sold the remaining half interest in his patent to the

Washburn and Moen Company, a major wire manufacturer, for $60,000 plus a percentage of royalties, making him a wealthy man. Ellwood joined with the company, which continued to manufacture and sell Glidden's invention.

Glidden returned to farming and local civic and business activities. He purchased more farmland and invested in businesses, including part or full ownership of the De Kalb National Bank, the Glidden Hotel, and the De Kalb Grist Mill. He continued collecting royalties but remained outside business operations, with the exception of court appearances to secure his patent rights. He served briefly as sheriff and ran the *De Kalb Chronicle*. After the death of his wife in 1895, he donated sixty-four acres of land and financial resources for the erection of Northern Illinois State Normal School in De Kalb County. The institution later became Northern Illinois University. Glidden died on October 9, 1906.

BARBED WIRE

Although Joseph Glidden is considered the "father of barbed wire," a man by the name of Michael Kelly had invented barbed wire six years before Glidden received his patent in 1874. However, Kelly's invention, which employed diamond-shaped barbs to form what he called a "thorny fence," did not find a large market and was eventually superseded by Glidden's fencing system.

After seeing a farmer's nail-like fencing at a county fair in 1873, Glidden was inspired to make his own product. Legend states that he was in his kitchen trying to determine a way to prevent animals from entering his wife's garden. Experimenting with a modified coffee grinder, he placed two pins on one end of it, one centered and the other just off-center to allow for a wire to slide through. When he hand-cranked the device, it twisted the wire into a loop, which was clipped to form sharp points. Glidden placed the barbs on a strand of wire and used an old grindstone to twist another length of wire around the first, locking the barbs into place. When the two-stranded barbed wire was lined across a field or pasture, the sharp prongs prevented livestock from leaning against the fence and prohibited outside intruders as well.

Barbed wire no doubt had a profound effect on the settlement of the American West, but it was also used as an implement of war. It was used in the Spanish-American War (1898) to secure buildings and protect ammunition dumps, and it was used more extensively during World War I (1914-1918). In addition to protecting secure locations and temporarily enclosing prisoners of war, large hedges of barbed wire were employed in front of trenches to slow frontal assaults. The barbs slowed oncoming forces by grabbing clothing, tearing skin, and forcing a slow approach to the trenches. Caught up in the sharp edges, charging soldiers became easy targets for rifle and machine gun fire. Barbed wire contributed to the lengthy stalemate World War I became before tanks were employed to crawl over it.

After World War I, barbed wire was used in prisons and concentration and prisoner of war camps to confine human detainees. The wire was used on top of walls, along boundaries, or inside camps to slow anyone attempting to cross. It was sometimes electrified to increase its effectiveness. Barbed wire was used in the boundary line between East and West Berlin during the early days of the Cold War and in some instances for the purpose of torturing humans. It has been erected in detainee and refugee camps and for crowd control in urban areas. In stark contrast to Glidden's promotional posters of the late nineteenth century, barbed wire has been negatively depicted in propaganda posters, literature, and paintings, usually to denote suffering or imprisonment.

IMPACT

The impact of Glidden's invention was far-reaching. Barbed wire spread rapidly throughout the plains as thousands of farmers contained and protected their livestock and enclosed their fields with the product. Barbed wire was inexpensive and easily obtained and erected. It lasted longer than wood, which was quickly replaced. Washburn and Moen sold millions of pounds of barbed wire annually to farmers throughout the American West.

Boon as it was to the homestead farmer, barbed wire was vilified by others. Cattle owners blamed Glidden's invention for ending the profitable cattle drives. While some ranchers used the wire to create boundaries for their property, cattlemen on the long drives from Texas reviled it. The cattle drives began in earnest after the end of the Civil War. Longhorn cattle in Texas were rounded up and driven northward across the open range along well-known cattle trails to northern railheads. In cattle towns such as Abilene and Dodge City, ranchers received a higher price for their stock, and railroads quickly transported them to eastern cities. As they moved northward, cowboys relied on the use of public lands, known as the open range, to transport, graze, and water their cattle. Farmers, tired of large herds overrunning their pastures and trampling their crops, erected barbed wire to keep them out.

The newly fenced fields prevented cowboys from accessing grazing pastures and watering holes, forcing them miles out of their way to find alternatives. Barbed wire cost them time and money, and some felt that their freedom to use the open range was not being protected. In addition, there were a few farmers who squatted on public lands and enclosed areas they did not own. With so much of the open range enclosed, it was no longer feasible to walk northward along the previously used trails. Additionally, barbed wire was blamed for a considerable number of cattle deaths during the devastating blizzards of 1886-1887. Cattle seeking shelter from the storms or searching for food ran up against the barbed wire and could go no further. Thousands of cattle carcasses were found piled against the fences when the drifted snows finally cleared.

Referring to barbed wire as the "devil's rope," a few westerners felt within their rights to cut the wire fences and continue on through. Fence-cutting raids usually occurred after dark when a small group could destroy a great deal of fence in one evening's raid. Fence openings allowed livestock to escape and run away. It permitted outside animals to invade crops and predators to attack livestock. Rustlers used the cut fences as an opportunity to steal. Farmers retaliated, sometimes violently, and so-called range wars broke out in the early 1880's. Men died in a few instances before legislation was passed making fence cutting illegal.

Barbed wire was challenged for possible cruelty to animals. The barbs were intended to hurt animals enough to discourage them from leaning against the fence and make them stay in the enclosures. However, if horses spooked or cattle stampeded, they could run headlong into the fence and cause severe damage to themselves. Hearings were held in a number of states, but the fencing won out, sometimes with the addition of a piece of wood or board to alert livestock of the wire's existence. Glidden's barbed wire helped settle the western United States, yet his invention was not confined to the United States or the nineteenth century. The agricultural uses of the fencing continue today.

—Leslie A. Stricker

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See also: Luther Burbank; George Washington Carver; John Deere; Cyrus Hall McCormick; Jethro Tull; Eli Whitney.

ROBERT H. GODDARD

American scientist

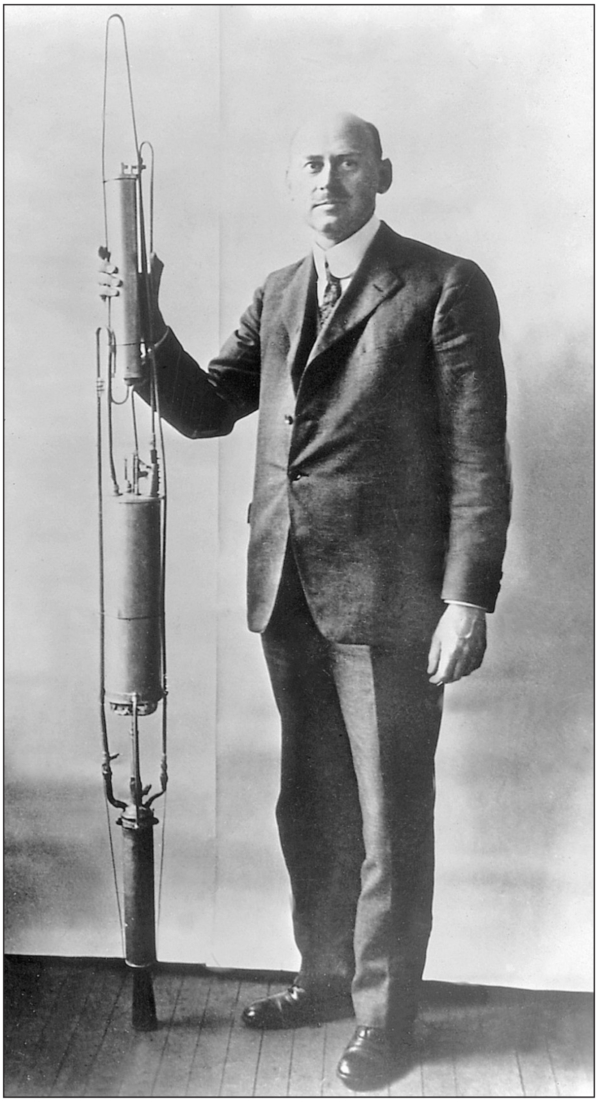
Goddard's vision of interplanetary rocket flight, laid out in a series of patents and articles dating from 1914, played a great inspirational role in the development of space exploration. He was first to launch a liquid-fueled rocket and first to break the speed of sound with a self-propelled machine.

Born: October 5, 1882; Worcester, Massachusetts
Died: August 10, 1945; Baltimore, Maryland
Also known as: Robert Hutchings Goddard (full name)
Primary field: Aeronautics and aerospace technology
Primary invention: Liquid-fueled rocket

Early Life

Born in Worcester, Massachusetts, the site of a thriving wire and machine tool industry, to a traveling salesman and machine shop superintendent, Robert Hutchings Goddard (GAHD-ahrd) grew up in a household accustomed to tinkering and invention. Space travel became a fascination for the young boy after he read Jules Verne and H. G. Wells. One fall afternoon in 1899, atop a cherry tree, Goddard envisioned a device ascending into the heavens all the way to Mars. In his diary, he wrote that he had been changed forever, and October 19 became "anniversary day" for the rest of his life. Although respiratory illnesses interrupted his secondary education for two years, he used his time at home to study electricity and chemistry, and eventually graduated in 1904 from Worcester's South High School as class president and with the highest honors. The concluding words of his graduation address have become a standard epigram for technological pursuits: "The dream of yesterday is the hope of today and the reality of tomorrow."

Goddard went on to Worcester Polytechnic Institute (WPI), majoring in general science, where he wrote imaginative college papers on such topics as train travel in a vacuum tube, the theory and uses of the gyroscope, "On the Utilization of Atomic Energy," and the "Possibility of Investigating Interplanetary Space." The essay on space exploration was rejected for publication by *Scientific American* and *Popular Astronomy*, which described the student's work as well written but impractical. However, in 1907, *Scientific American* did publish his article on "The Use of the Gyroscope in the Balancing and Steering of Aeroplanes." His senior thesis explored the electrical properties of powders, a topic he continued to pursue in his graduate studies.



Robert H. Goddard with a liquid-fueled rocket in 1926. (Library of Congress)

Life's Work

From 1909 to 1911, Goddard pursued his Ph.D. in physics at Clark University, finishing with a dissertation "On the Conduction of Electricity at Contacts of Dissimilar Solids," which had implications for radio waves. On May 4, 1915, he was issued a patent on a "Method of and Apparatus for Producing Electrical Impulses or Oscillations," the third patent of 214 eventually registered in his name. Goddard's interest in rocketry had not flagged, and, in 1917, he was granted use of WPI's Magnetic Building (formerly a laboratory for electromagnetic experimentation) to conduct experiments on solid-fuel rocket propulsion. Although for much of his career he was on a leave of absence, Goddard retained his association with Clark University as chair of both the physics and mathematics departments until two years before his death.

Goddard's fame would ultimately rest with his work on liquid-fueled rockets, but because of the difficulty of acquiring the necessary propellants, he began his career experimenting with multifiring powder rockets that would in theory lift themselves by the recoil of a series of explosions. The concept rested on Sir Isaac Newton's third law of thermodynamics, that every action produces an equal and opposite reaction, which holds true even in a vacuum. After the Smithsonian Institution published his seminal essay on "A Method of Reaching Extreme Altitudes" in 1919, the headlines of newspapers in Boston, New York, Chicago, San Francisco, and elsewhere proclaimed extravagantly that the inventor had created a rocket capable of reaching the Moon. Although an editorial at *The New York Times* ridiculed the inventor's belief that one could fly across a vacuum (an error acknowledged by the paper when Apollo 11 roared off in 1969), Goddard had brought the fantastic dream of voyaging to the Moon into public consciousness.

Goddard's career as a full-time rocketeer had begun on January 5, 1917, when he received his first grant of $5,000 from the Smithsonian, which continued to support his work monetarily until 1934. In order to give his experimentation a greater practical value so that he could secure funding, the rocketeer had sold the merits of rocket development as a means of lifting meteorological equipment to study the upper atmosphere. Seeking other sources of funding toward the end of World War I, he developed a tube-launched infantry rocket, a prototype of the bazooka used in World War II. Always something of an absentminded professor in his personal life, Goddard brought more order to his life by his marriage on June 21, 1924, to Esther Christine Kisk (1901-1982).

The beginning of the space age can be arguably traced back to March 16, 1926, when, on the farm of a distant relative in Auburn, Massachusetts, Goddard launched a rocket fueled by a mixture of gasoline and liquid oxygen some forty-one feet into the air. News of his work reached the famous aviator Charles A. Lindbergh, who flew to Worcester to meet Goddard in 1929 and supported his efforts to secure a two-year grant from Daniel Guggenheim, who with his son Harold had created the Guggenheim Fund for the Promotion of Aeronautics. A promise of $100,000 to be awarded over four years allowed Goddard to locate in Roswell, New Mexico, where he could pursue year-round rocket launches. From 1931 to 1932, he conducted experiments on the use of gyroscopes and blast vanes to stabilize rocket flights. The death of his benefactor in 1930 led to an interruption in funding and Goddard's resumption of his teaching duties at Clark. However, Harold shared his father's enthusiasm for aeronautics and faith in Goddard, and the rocket crew resumed launches in Roswell in 1932.

Here Goddard enlarged the combustion chamber, using pressurized nitrogen gas to force fuels rapidly into the chamber, and developed the method of curtain cooling to prevent the chamber from overheating. The rocket, affectionately called "Nell," was contained in a duralumin shell, weighed eighty-five pounds, and stretched fifteen feet in length. On March 8, 1935, one of his rockets exceeded the speed of sound and in May and July reached one mile in altitude. On March 26, 1937, Rocket L-13 exceeded 8,000 feet of altitude, and, on August 9, 1938, a National Aeronautic Association record was officially established at 6,565 feet (3,294 feet above sea level).

With the outbreak of World War II, Goddard turned his efforts toward the development of rocket-assisted takeoffs for Army Air Forces and Navy aircraft, and from 1942 until his death from throat cancer in 1945 in a Baltimore hospital, he worked at the Naval Engineering Experiment Station in Annapolis, Maryland. During this time, he also served as an engineering consultant to the Curtiss-Wright Corporation of Caldwell, New Jersey. Robert Goddard's legend continued to grow after his death, particularly because of the work of his protective and energetic wife, Esther, who devoted her life to memorializing her husband's legacy.

IMPACT

Goddard changed the nature of the rocket motor by application of a de Laval nozzle, proved that rockets would work in a vacuum, and developed designs for multistage and liquid-fueled rockets. He received 83 patents during his lifetime and was awarded 131 more after his death. However, since he guarded his work closely and worked largely alone with his small crew, his actual influence on the technological development of modern rocketry was limited. Goddard claimed that the frightening trajectory of the Nazi V-2 rocket was the result of surreptitious theft of his patents, when in fact German success was the result of the natural evolution of research under the much greater governmental support for rocket development under the Third Reich. Scholars have also argued that Goddard could have accomplished more if he had proceeded with more systematic, step-by-step experimentation rather than attempting several innovations at once in

THE LIQUID-FUELED ROCKET

On March 16, 1926, Robert H. Goddard made history when he launched his first liquid-fueled rocket. It was ten feet tall, weighed 10.5 pounds when loaded, and used liquid oxygen and gasoline as fuel, giving about five times per pound more energy than trinitrotoluene (TNT). The propellants were stored in rear tanks and piped to the motor in the front, because Goddard initially believed that pulling the rocket would give greater stability than pushing it. The rocket rose out of a light, portable metal framework. Preliminary heating by a small alcohol stove created gas pressure to force the fuels, which were simply ignited by a long blowtorch, into the motor. On the first flight, the propellants burned for twenty seconds before liftoff, burning off a portion of the nozzle before sending the vehicle at sixty miles per hour some forty-one feet into the air, where it yawed over toward the ground 184 feet away. This first experiment led Goddard eventually to develop stabilizing vanes on the thrust nozzle controlled by a gyroscope and to the idea of a staged rocket that would lessen its weight by discarding spent fuel sections.

the hope of reaching higher altitudes. Team collaboration among scientists and inventors was the ultimate route to the stars. Nevertheless, in spite of many failed rocket experiments, Goddard persevered, and dozens of his ideas became standard features in space technology after World War II.

After Goddard's death, Esther began a campaign to secure recognition for his accomplishments and pursued a patent-infringement claim against the federal government, winning in 1960 $1 million for the Daniel and Florence Guggenheim Foundation. Congress ordered a special gold medal struck in his honor, and the American Rocket Society and the American Institute of Aeronautics and Astronautics created Goddard awards. Undoubtedly the greatest tribute to the father of modern rocketry is the NASA Goddard Space Flight Center in Greenbelt, Maryland, established in 1959. As a visionary of the possibility of space travel, Robert Hutchings Goddard should stand with Konstantin Tsiolkovsky (1857-1935) and Hermann Julius Oberth (1894-1989) as the inspirations for modern rocketry.

—*Bland Addison*

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See also: Wernher von Braun; Frederick Gardner Cottrell; Burt Rutan; Henry Thomas Sampson; Konstantin Tsiolkovsky.

LEOPOLD GODOWSKY, JR.

American photographic technician and musician

Godowsky, along with Leopold Mannes, invented Kodachrome film, which has been widely regarded as the best color film available for still and slide photography as well as for home movies.

Born: May 27, 1900; Chicago, Illinois
Died: February 18, 1983; New York, New York
Primary field: Photography
Primary invention: Kodachrome color film

Early Life

Leopold Godowsky, Jr. (goh-DOW-skee) was born in Chicago, Illinois, on May 27, 1900. Leopold Godowsky, Sr., was a famous pianist who at the time of his son's birth was the head of the piano department at the Chicago Conservatory. Young Leopold's mother was Freida Saxe. Shortly after his son's birth, Godowsky moved his family to Berlin, Germany, where he performed and taught music until the outbreak of World War I, when the family moved back to the United States and settled in New York City. The Godowsky home was visited by many celebrities, including Albert Einstein and Sergei Rachmaninoff, so young Leopold enjoyed the influence of many of the great minds and musicians of the day. While a young boy, Leopold began studying the violin.

While in high school, he met Leopold Mannes. Mannes, who later became a concert pianist, and young Godowsky became fast friends. In 1917, while still in high school, they went to see an early color movie, *Our*

Navy. The boys were very disappointed by the quality of the color, and they began tinkering with improving color photography. They built a movie projector and fitted it with three lenses, each with a different color filter. They then took black-and-white movies and projected them through the red, blue and yellow filters to produce a color film. The boys received a patent for their invention, but it was too cumbersome to be of any commercial use.

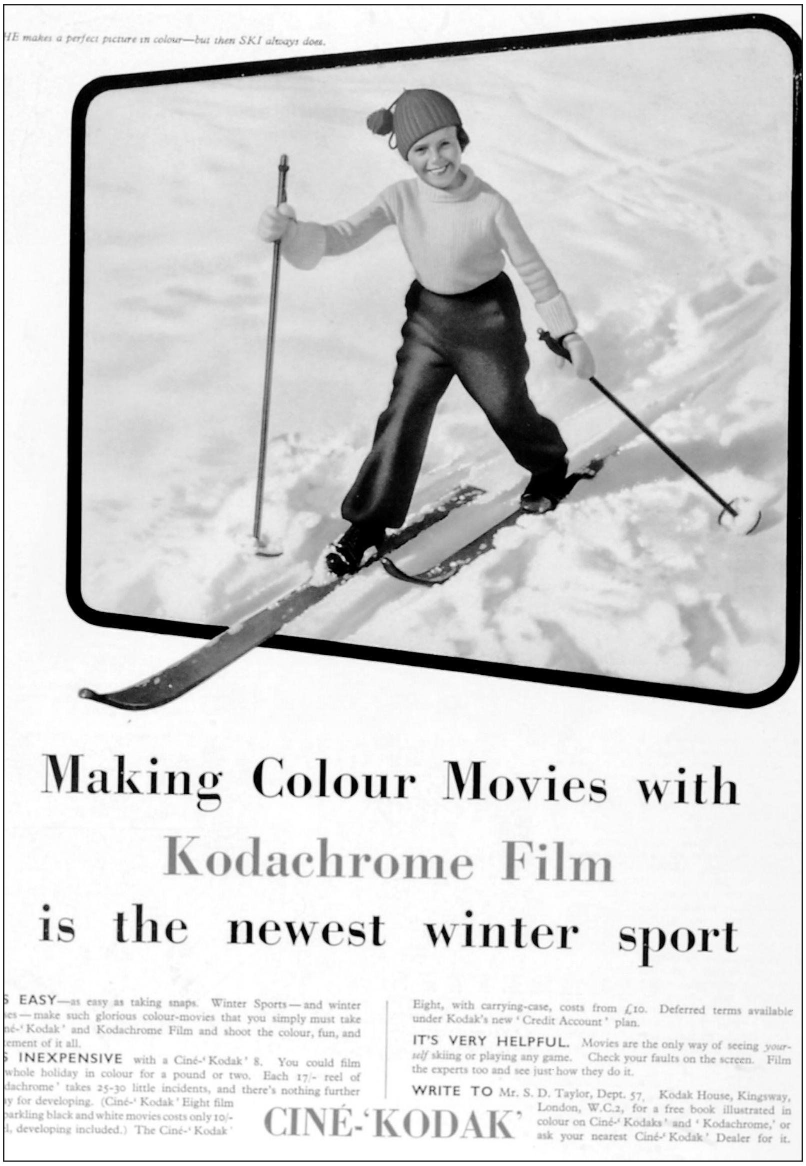
Life's Work

After high school, Godowsky moved to the West Coast, where he attended the University of California, Los Angeles (UCLA), to study physics and chemistry as well as violin. Mannes went to the East Coast to study physics and piano at Harvard University. After graduation, Godowsky became a soloist and first violinist with the Los Angeles and San Francisco Symphony Orchestras and also performed with his father, while Mannes moved to New York City. Although separated by a continent, the two continued their friendship and their joint interests in music and improving color photography.

In 1922, Godowsky moved to New York City, where he teamed up with Mannes, and they began performing together. They now finally had an opportunity to collaborate on their color photography research. They worked in their apartments, where in their bathrooms they could achieve total darkness for developing film. Unable to see their watches, they timed the developing process by whistling the last movement of Brahms's C-minor Symphony, pacing the music with a metronome set at two beats per second.

Later that year, Mannes traveled to Europe to perform as a soloist. On his way there, he chanced to meet a senior partner of the investment firm Kuhn, Loeb and Co., and told him about his color photography research. After Mannes returned to New York, the firm sent one of its associates, Lewis L. Strauss, to Mannes's home to further investigate their work. Impressed, the firm offered to invest in their project.

With money in hand, Godowsky and Mannes could step up their color photography experiments. They built a laboratory to work in, and within a year they were able to receive patents for their work. Eastman Kodak became interested in their film and offered them a contract to move to the Kodak research facilities in Rochester, New York, to continue their development of their film. Three



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CINÉ-'KODAK'

An advertisement for Kodachrome in the December, 1938, issue of the English weekly magazine Illustrated Sporting and Dramatic News. (Popperfoto/Getty Images) years later, Godowsky and Mannes had a commercially viable three-color emulsion process for home movie film ready to be marketed. This film, Kodachrome 16mm film, was put on the market in 1935. It was followed the next year by Kodachrome 25mm still and 8mm movie films. Their associates jokingly commented that Kodachrome had been invented by "God and Man," a reference to the first three letters of each of their names.

KODACHROME

The development of Kodachrome film marked a major leap forward in the quality and durability of color film. Before Kodachrome, color film had emulsion layers, but their dye couplers were incorporated into the layers when produced; after exposure, all three layers were developed at the same time. Kodachrome did not include the dye couplers in the production of the film but instead added them during the development process. By not adding the dye couplers during production, Kodachrome could use thinner emulsion layers. Thicker layers cause more light to scatter, reducing the sharpness of the photographic image.

The different development process utilized by Kodachrome was much more complicated than that of the older films, and it required large machinery run by trained technicians with chemistry training. Thus, the development of Kodachrome film could not be done by amateur photographers or even by most small commercial processing laboratories. When Kodachrome was first introduced in 1935, the price included Kodak processing. The package of film included a self-addressed mailer so that the purchaser could send the exposed film to a Kodak laboratory, where it was processed and then returned by mail.

The development process for Kodachrome is called the K-14 process, and it has several steps. First, the backing material is removed in an alkaline bath and wash. Then the first developer is added. The top layer of the film is the blue-sensitive yellow filter layer. A PQ developer is added, which changes the silver halide crystals to metallic silver. This makes the yellow filter layer opaque. Then the film is washed to remove excess developer.

The film is then exposed to red light, which readies the silver halide in the cyan layer. A developer and cyan coupler are added to develop this layer. The film again is washed to remove excess developer and is then exposed to blue light to ready the blue-sensitive layer. The already opaque yellow filter keeps the blue light from affecting the magenta layer, which is sensitive to both blue and green light. Finally, another developer is added to develop the yellow layer, and again the film is washed. The last bath develops the magenta layer, and again the film is washed.

The film then goes through several steps to clean and fix it. First, a conditioner is added, and then bleach, to oxidize the metallic silver back to silver halide. Then a fixative is added that converts the silver halide to soluble compounds that can then be washed out of the film. After a rinse that contains a chemical to prevent water spots, the film is dried.

The result of this processing procedure is that Kodachrome films have no unused color couplers remaining that can contribute to film and color deterioration, so the film has good dark-storage stability.

Kodachrome used three layers of black-and-white film. Each layer was suspended in a different colored filter material such that each layer was sensitive to either red, green, or blue. This was the first time that color film had been introduced as an integral tripack film. When the film was processed, color dyes replaced the silver halides. This developing process allowed the film to have thinner layers than older color films, resulting in sharper pictures.

After inventing Kodachrome, Mannes returned to his music career. Godowsky, however, while also returning to performing, continued to work on improving Kodachrome in his own laboratory in Westport, Connecticut, until the 1950's.

Despite Godowsky's success as the inventor of Kodachrome, his first love was always music. He continued his family's musical tradition when he married Frances "Frankie" Gershwin, the younger sister of George and Ira Gershwin. Frankie had been the first of the Gershwin siblings to perform publicly. After her marriage to Godowsky, she continued her artistic bent as a painter and a sculptor. In 1975, she returned to singing, recording an album titled *For George and Ira*. The Godowskys had four children: Alexis Gershwin, Leopold Godowsky III, Georgia Keidan, and Nadia Natali. All four enjoyed the arts, with Leopold III following in this grandfather's footsteps by becoming a concert pianist.

Godowsky died in Manhattan, New York City, on February 18, 1983. Godowsky and Mannes were inducted into the Inventors Hall of Fame in 2005. Boston University's Photographic Resource Center gives an award for color photography biennially in honor of Godowsky.

IMPACT

The careers of Godowsky and his partner Mannes demonstrate that individuals can dedicate their lives to one vocation and at the same time can have an unrelated but important avocation as inventors. Godowsky's passion was music, but his fascination with color photography and his desire to produce a quality, affordable film kept him persevering for eighteen years. His college education included music as well as the chemistry and physics that would inform his research on color photography.

The fruit of their labors was an easy-to-use film with exceptional quality and color accuracy that was equally popular with amateur and professional still and movie photographers. Kodachrome's superior dark-storage longevity allowed amateur photographers to preserve family photo albums and home movies for generations. Folk singer Paul Simon wrote about his appreciation of the qualities of the film in his hit song "Kodachrome."

Perhaps more important, the storage longevity has permitted the archiving and preservation of thousands of historic images ranging from color movie footage of World War II events to Steve McCurry's *National Geographic* portrait of Sharbat Gula, the "Afghan Girl." In February, 2000, footage taken by George Jefferies of John F. Kennedy ninety seconds before he was assassinated was found and was still in excellent condition. The Sixth Floor Museum in Dallas, Texas, has this footage on display.

Godowsky and Mannes were first inspired to work on color photography after viewing a disappointing color movie in 1917. Their first goal was to produce a method to make improved commercial color movies. However, the Technicolor Motion Picture Corporation developed Technicolor in 1922, and it was this invention that went on to be widely used by the motion-picture industry.

—Polly D. Steenhagen

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See also: Louis Jacques Daguerre; George Eastman; Gabriel Lippmann; Leopold Mannes.

PETER CARL GOLDMARK

Hungarian American engineer

Goldmark invented the long-playing phonographic record, which revolutionized recorded sound and dominated the music industry for four decades. He also produced a system for transmitting and receiving color-television images and contributed to the development of audiocassettes and videocassettes.

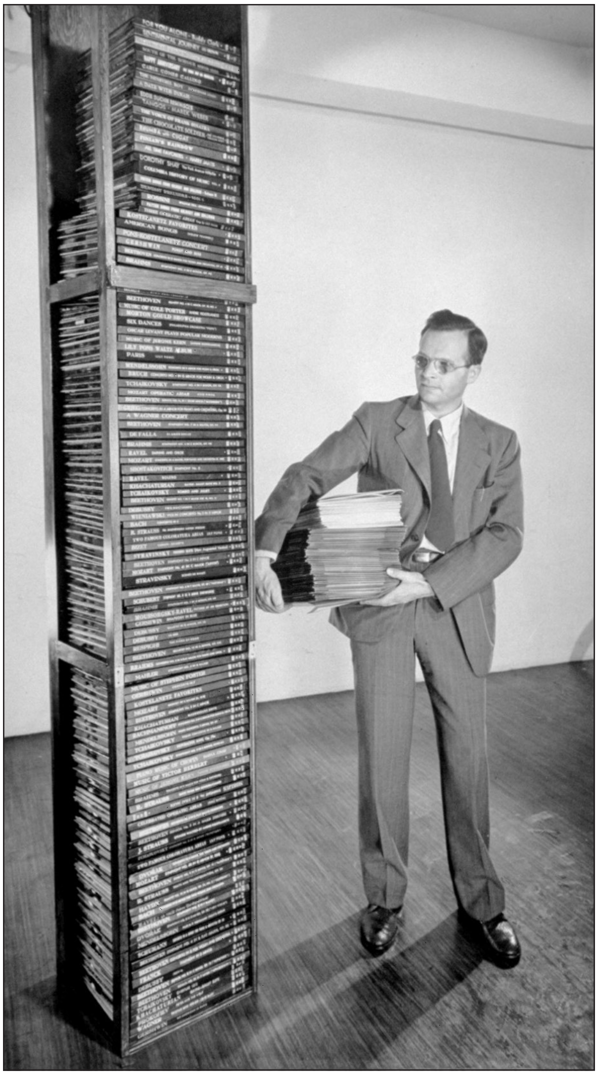
Born: December 2, 1906; Budapest, Hungary
Died: December 7, 1977; Rye, New York
Primary fields: Communications; electronics and electrical engineering; physics
Primary inventions: Long-playing (LP) record; color television

Early Life

Peter Carl Goldmark was born in Budapest, Hungary, in 1906, the eldest child of Alexander Goldmark and Emma Steiner. His father was a businessman, and his great-uncle, Joseph Goldmark, was a chemist and inventor. Young Peter grew up in a musical household and was influenced by his musical mother and another great-uncle, Karl Goldmark, who was one of Hungary's greatest classical composers. Peter learned the piano and cello as a child, and his interest in music undoubtedly influenced his later work with sound recording. He was also fascinated by machines and science.

After his parents divorced when he was eight years old, Peter and his mother moved to Vienna, where he set up a home laboratory in the bathroom. He built a radio telegraph receiver and developed an interest in contemporary devices that were used for showing motion pictures. During this period, he also applied for his first patent for an invention that allowed an automobile driver to activate a horn with his knee.

In 1925, Goldmark attended the University of Vienna to study physics. A year later, he obtained a primitive televison kit from Scottish engineer John Logie Baird, who is generally credited as being the first person to successfully transmit a television image (in 1925). Goldmark modified and enlarged the small screen, which had been about the size of a postage stamp, and became intensely interested in television electronics.



Peter Carl Goldmark stands next to a storage tower holding hundreds of 78-rpm records while he holds long-playing records (LPs) with the same amount of music. (Time & Life Pictures/Getty Images)

After graduating with a Ph.D. in 1931, Goldmark began working as a television engineer for Pye Radio in Cambridge, England. A few years later, he moved to the United States, and in 1936 he became the chief engineer for the Columbia Broadcasting System (CBS) in New York. He became a U.S. citizen the following year. At CBS, Goldmark was instrumental in developing a television department for the company, and he went on to revolutionize the recording industry with the invention of vinyl phonographic records.

LIFE'S WORK

Throughout his career, Goldmark was awarded numerous patents for his inventions. During World War II, he developed electronic jammers that were used by pilots to disrupt enemy radar, and his devices were used during the Allied invasion of Normandy.

During a trip to Montreal in 1940, Goldmark saw a screening of *Gone with the Wind* (1939), one of the first motion pictures filmed in color. He was impressed with the Technicolor format of the movie. At the time, television was in its early stages, and pictures were still broadcast in black and white. Goldmark became determined to develop a method to colorize TV images. Within months, he had developed his field-sequential system, which was demonstrated for the first time in New York in the summer of that year. The method used a rotating disk of three color filters (red, blue, and green), which were placed in front of the camera and synchronized with a similar disc in the TV set. The result was a sharp, colorized image. Unfortunately, Goldmark's method was not compatible with the millions of existing black-and-white televisions and would have required consumers to purchase new TV sets.

The Radio Corporation of America (RCA) also developed a method to transmit color images that was compatible with existing black-and-white TV sets. Although image quality was inferior to Goldmark's, the RCA method was eventually approved by the Federal Communications Commission (FCC) and became the industry standard when color television was introduced in the United States in 1951. Due to the outstanding quality of Goldmark's system, it was still used for medical and educational applications that required closed-circuit television. Years later, Goldmark's lightweight system was used by the National Aeronautics and Space Administration (NASA) to broadcast color images during the Apollo 11 Moon landing.

Goldmark's most important invention originated from his interest in music. During a casual evening at a friend's home in the fall of 1945, his dinner host played a recording of Brahms's Second Piano Concerto. Six records were required to play the fifty-minute piece, and the frequent interruptions to the music by changing and flipping the records irritated Goldmark. These early records spun on a turntable at 78 revolutions per minute (rpm) and relied on a steel needle to trace the record grooves to produce sound. Each time a record was played, however, both the needle and the brittle shellac discs became worn and damaged, making the already poor sound quality even worse. Goldmark immediately began a quest to find a replacement for these discs and improve sound recording technology.

After working on the project for three years, Goldmark produced a record with much thinner microgrooves. He increased the width of the record by several inches (to twelve inches) and slowed the revolution speed to 33⅓ rpm. This increased playing time to over twenty minutes for each side, allowing for most popular classical works to fit on one disc. The new records were made of lightweight vinyl and were virtually indestructible. He also replaced the old steel needles with sapphire, extending the lifetime of the record and needle considerably, and made improvements to the recording microphone to produce a clearer and cleaner sound.

The first long-playing record was demonstrated in 1948 and featured Goldmark playing the cello accompanied by other CBS employees playing other instruments. Although LPs were not an immediate commercial success, the popularity of the Broadway hit musical *South Pacific* (1949) boosted LP sales enormously. Longtime competitor RCA quickly marketed 45 rpm "singles" for individual popular songs, but the LP dominated the music industry for forty years until it was displaced by the compact disc in the 1980's.

During his years at CBS, Goldmark was promoted several times and eventually became president of the CBS Laboratories. While at CBS, he worked on developing a new audio system that could be played in automobiles. Chrysler models (1956-1959) used the system that was called Highway Hi-Fi. It was installed below the car's instrument panel in a shock-proof case and used special seven-inch discs with ultramicrogrooves. Because the devices were prone to malfunction, the concept was not pursued by CBS, which also feared that drivers would spend less time listening to CBS radio stations while driving. The idea eventually led another company (Philips) to develop audiocassettes that used magnetic tape to store sound and cassette decks that could be easily installed in automobiles. Goldmark also aspired to create a system for recording both sound and pictures on tape; his Electronic Video Recording system eventually evolved into the videocassette that was developed by Sony in 1971.

Goldmark left CBS in 1971 to form his own company, Goldmark Communications Corporation, in Stamford, Connecticut. While he continued to be involved in researching new communication technologies (for example, satellites and cable television), he devoted more time to humanitarian issues, promoting education, and using technology to increase peoples' quality of life. In 1977, the same year he was awarded the National Medal of Science by President Jimmy Carter, Goldmark was killed in an automobile accident in Westchester County, New York.

THE LONG-PLAYING RECORD

The vinyl, long-playing (LP) record evolved from an original recording method invented by Thomas Alva Edison, who first recorded sound in 1877. Sounds produce vibrations in the air molecules, which conduct waves to the eardrums, where the vibrations are detected and transmitted via nerves to the brain. To record sounds, a device is needed to capture the air vibrations and convert them into a form that can be stored on a master disc, which can then be copied for duplication and mass production.

Peter Carl Goldmark's LP records contained up to 350 V-shaped grooves per inch. The grooves contained tiny hills and valleys that represented the sound waves recorded on the disc. As a sharp diamond or sapphire needle (or stylus) followed the groove around the record, it produced vibrations that were converted into electrical signals. Since the output signals were very weak, an amplifier was needed to magnify the signal to make the recorded sounds audible. Goldmark's LPs were made of soft, polyvinyl chloride (PVC), which was pressed between two hot molds that contained the original master recording to produce the copy. It took about twenty-five seconds to stamp each record.

Records were protected in a thin cardboard case, or album, which usually featured colorful and detailed artwork on the cover. Long after the popularity of LPs declined, vinyl records were still sought by collectors.

IMPACT

Goldmark produced more than 150 inventions, many of which had an influence on society and improved the quality of life for humanity. His technology-based communications products were both functional and fun, improving leisure activities. His discoveries in the areas of electronics and communications were especially significant in expanding the entertainment industry and advancing education.

By providing thousands of artists with the means to record their songs, Goldmark's long-playing records became a worldwide industry and popular form of entertainment. Compared to early records, his lightweight, vinyl discs reduced shipping and storage costs, resulting in huge savings for consumers, producers, and retailers. By the 1970's, annual sales of LP records in the United States were over a quarter million. LP records had an enormous impact on the economy, creating many jobs and opportunities for people in the entertainment and arts industries.

From the mid-1950's and beyond, record players or stereos were purchased by millions of families and, together with televison sets, introduced the electronics revolution to consumers around the world.

—*Nicholas C. Thomas*

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See also: Ernst Alexanderson; Emile Berliner; Thomas Alva Edison.

CHARLES GOODYEAR

American chemist and businessman

Goodyear's vulcanization process, modified but essentially the same today, transformed rubber from an almost useless, smelly substance that was sticky in summer, hardened and cracked in winter, and soluble in solvents into a versatile, stable, commercial product with hundreds of uses.

Born: December 29, 1800; New Haven, Connecticut
Died: July 1, 1860; New York, New York
Primary fields: Chemistry; manufacturing
Primary invention: Vulcanized rubber

EARLY LIFE

Charles Goodyear, the oldest son of Amasa Goodyear and Cynthia Bateman Goodyear, was born in New Haven, Connecticut, on December 29, 1800. His father was an inventor as well as a manufacturer of farm implements and hardware. The family included seven inventors within four generations. The studious and quiet Charles attended school in Naugatuck, Connecticut. In 1817, he was apprenticed to a hardware manufacturer and importer in Philadelphia, Pennsylvania. In 1821, he returned to New Haven to join his father's business. On August 24, 1824, he married Clarissa Beecher, the daughter of a Naugatuck innkeeper. They had nine children.

In 1826, in Philadelphia, the father and son founded the first domestic hardware store in the United States, but because of overextended credit they became bankrupt. For the rest of his life, Goodyear was usually poor and often spent time in debtors' prisons, where he performed most of his experiments on rubber. Often he needed to sell furniture and household items to procure food for his growing family. He became an inventor and was preoccupied with rubber, which he unsuccessfully attempted to use in his inventions. During the period 1830-1834, he was issued six patents on mechanical devices.

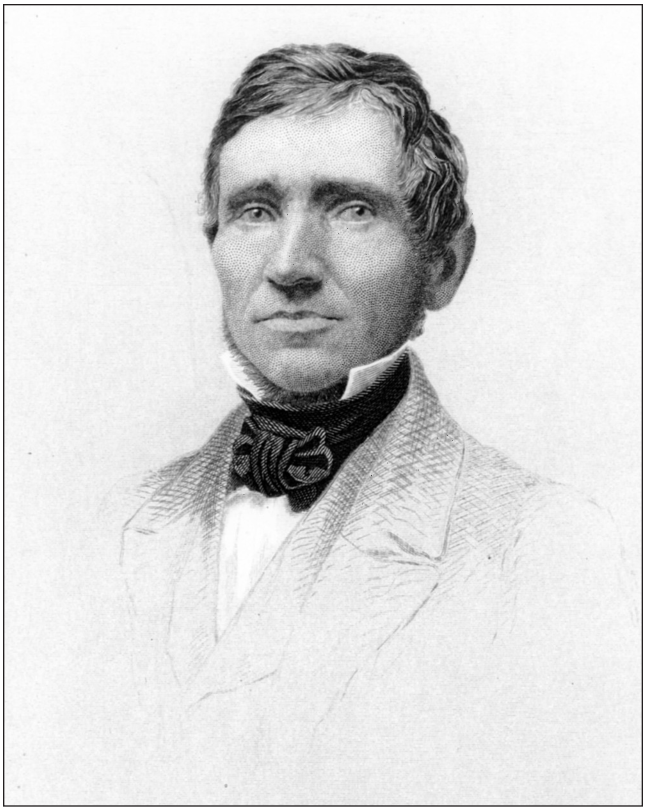
Life's Work

Rubber, obtained from the tree *Hevea brasiliensis*, a member of the Spurge family, is one of the longest-known natural materials. The ancient Egyptians, Ethiopians, and various Asian and African peoples depicted games with bouncing rubber balls in pictures or carvings. Indians of the Amazon basin knew of its properties and uses long before Christopher Columbus (1451-1506) brought it to the attention of Europeans. Spanish historian and navigator Gonzalo Fernández de Oviedo y Valdés (1478-1557) and historian Antonio de Herrera y Tordesillas (1559-1625) described balls used by the Indians. French geographer Charles Marie de La Condamine (1701-1774) brought rubber from the Amazon to Europe.

However, rubber remained a mere novel curiosity. It was used to a small extent to waterproof shoes, boots, and clothing, which were called "mackintoshes," named for Scottish inventor Charles Macintosh (1766-1843). When cold, the rubber hardened and cracked, and when warm, it melted or became sticky. In 1770, English clergyman and chemist Joseph Priestley (1733-1804) called it "rubber" since it could be used to erase pencil marks from paper.

In 1820, English inventor and coach maker Thomas Hancock (1786-1865), who later pirated Goodyear's vulcanization process because Goodyear was denied an English patent, founded the world's first rubber factory. In the summer of 1834, Goodyear visited the Roxbury India Rubber Company's New York City salesroom, where he learned of the problems faced by the new industry. Recognizing rubber's valuable properties—strength, plasticity, durability, electrical nonconductance, and resistance to water—he became intrigued by this peculiar elastomer and devoted the remainder of his life to improving, promoting, and exhibiting it to the detriment of his health and family finances.

Neither a chemist nor scientist, Goodyear used trial-and-error methods, later made famous by Thomas Alva Edison (1847-1931). In 1835, Goodyear received the Mechanics Institute of New York's silver medal for his development of rubber sheeting. Unfortunately, in hot weather the product softened and became sticky. He bought the Eagle India Rubber Company of Woburn, Massachusetts, in 1838 from Nathaniel M. Hayward (1808-1865), who then worked for him. Hayward added small amounts of sulfur to his rubber compounds and exposed them to the sun. He patented this "solarization" process and sold the rights to Goodyear. If he had used a higher degree of heat (which most manufacturers avoided because it caused rubber to melt) rather than sunlight, he, rather than Goodyear, might have discovered vulcanization.



Charles Goodyear. (©Smithsonian Institution)

After more than five years of unsuccessful experiments, in January, 1839, Goodyear accidentally put a sample of rubber mixed with sulfur and lead monoxide (litharge) on a hot stove. This chemical reaction of rubber with sulfur at high temperature, which is still poorly understood, converted the sample into a substance that would have versatile commercial product potential. William Brockedon, a friend of both Goodyear and Hancock, suggested that the process be called "vulcanization," for the Roman god of fire and metalworking, a term that Goodyear repeatedly but reluctantly used.

Goodyear immediately applied his new process to

VULCANIZED RUBBER

Before vulcanization, the only method to seal small gaps between moving machine parts—for example, between a cylinder and piston in a steam engine—was to use leather soaked in oil, which could leak or create extra friction if packed more tightly. Vulcanized rubber could be formed into exact shapes and would comply with moderate to large deformations under pressure and would revert to its original dimensions when the pressure was removed. This property as well as durability and lack of stickiness made it a useful sealing material.

Unvulcanized natural rubber is a polymer made up of long hydrocarbon (carbon and hydrogen) chains, which can move independently toward each other, resulting in an irreversible change of shape. During vulcanization, cross-links are formed between the chains so that they can no longer move independently of each other. Therefore, on application of stress the rubber will be deformed, but on release of stress it reverts to its original shape.

Vulcanization is an irreversible process, and vulcanized rubber is a thermosetting polymer, which does not melt on heating, in contrast to thermoplastic polymers such as unvulcanized rubber, polyethylene or polypropylene, which melt on heating. In vulcanization, the cure agent is usually sulfur, which forms the cross-links, as in Charles Goodyear's original process, but peroxides are sometimes used. Also added are accelerators, such as zinc oxide or stearic acid, which speed up the reaction and decrease the curing time, and retarding agents, which prevent vulcanization from occurring prematurely.

On the rubber molecule, so-called cure sites, usually those with unsaturated (double) carbon-carbon bonds, attract sulfur atoms, which are formed by the breakdown of the naturally occurring six-membered sulfur rings. The length of the sulfur bridges or cross-links, usually between two and eight atoms long, influences the physical properties of the cured rubber. Short cross-links (one or two sulfur atoms) provide excellent resistance to heat, and longer cross-links (six or seven sulfur atoms) provide good dynamic properties—such as flexing movements for the final product needed for the movement of a tire's sidewall—but less resistance to heat. Because the cross-linked polymer possesses strong forces between the chains, it is insoluble, infusible, and thermosetting. The most important vulcanization method employs high temperature (170° Celsius, or 338° Fahrenheit, for passenger tires) and pressure.

The primary problem in recycling discarded tires, the most important of the hundreds of products made of rubber, has been to devulcanize them by delinking the sulfur atoms without losing the rubber's desirable properties. However, recycling processes have failed to yield consistent quality such that the product is unsuitable for use in many products, including tires, and recycled rubber has not been used to replace new or synthetic rubber in significant amounts.

Thanks to Goodyear's revolutionary discovery of vulcanization, this versatile elastomer has become indispensable to a variety of industries and products. The modern world, with its myriad necessities and luxuries, would be unthinkable without natural or synthetic rubber.

manufacturing various articles. By 1842, he was manufacturing rubber sheets, and by 1843, when he went bankrupt and was sent to debtors' prison, he was manufacturing other articles. He received a U.S. patent for his vulcanization process on June 14, 1844, and profits and license fees permitted him to pay his creditors.

Because his vulcanization process was so simple, numerous people used it without paying royalties, and Goodyear spent much time contesting as many as sixty patent infringements. The most famous of these, "the great India rubber case," was filed in 1851 against Horace H. Day, probably the most flagrant of the infringers. One of the greatest American business lawsuits of the nineteenth century, the case received widespread press coverage since Goodyear's main attorney was U.S. secretary of state Daniel Webster (1782-1852). Although Goodyear's claim was upheld on September 28, 1852, he spent time in U.S., English, and French debtors' prisons since he spent all his funds on inventions, experiments, and exhibitions.

A dedicated missionary for rubber, Goodyear spent six years in Europe championing its applications. Six weeks before Hancock's English patent was issued (May 30, 1844), Goodyear was issued a French patent (April 16, 1844), the first in any country for vulcanization, but because he had sent several American-made rubber shoes to France before his French patent, he was deprived of all his rights. Emperor Napoleon III (1808-1873) awarded him the Grand Medal of Honor and the Cross of the Legion of Honor. At the time of the second award, Goodyear was in Clichy, the Parisian debtors' prison.

In March, 1853, Goodyear's wife died, and on May 30, 1854, he married Fanny Wardell, an Englishwoman, who bore him three children, only one of whom survived its father. In 1858, Goodyear returned to New Haven, supposedly pawning his wife's jewelry to pay for their passage. On July 1, 1860, he died in New York City, where illness had forced him to rest en route to the funeral of the third daughter of his first marriage, Cynthia. He left behind debts of $200,000-$600,000.

IMPACT

Rubber technology has advanced since Goodyear's lifetime to the extent that rubber companies are among the world's largest corporations. Most of the world's rubber is used in the manufacture of tires, an application that Goodyear failed to foresee. More than half of rubber tires are now synthetic. In 2000, an unprecedented recall of millions of truck tires for Ford sport utility vehicles and pickup trucks in the United States became front-page news around the world. Goodyear's name is preserved in Goodyear tires and the Goodyear blimp, but neither Charles Goodyear nor any of his family or descendants was connected with the Goodyear Tire and Rubber Company. Its founder, Frank A. Seiberling (1859-1955), named it to honor the founder of an industry indispensable in modern life who was one of the United States' most famous inventors. Goodyear was inducted into the National Inventors Hall of Fame in 1976.

—*George B. Kauffman*

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See also: John Boyd Dunlop; Charles Macintosh; Joseph Priestley.

GORDON GOULD

American physicist

Gould coined the word "laser" (light amplification by stimulated emission of radiation) to describe his invention. One of the most significant technological advances ever, the laser became an essential tool in research, communications, medicine, military training, aerospace technology, commerce, and manufacturing.

Born: July 17, 1920; New York, New York
Died: September 16, 2005; New York, New York
Also known as: Richard Gordon Gould (full name)
Primary fields: Optics; physics
Primary invention: Laser

EARLY LIFE

On July 17, 1920, Richard Gordon Gould (gewld) was born the oldest of three sons in Manhattan, New York. His father, Kenneth Miller Gould, was descended from New England Puritans and was an editor of *Scholastic* magazine. He also wrote *They Got the Blame* (1942), a book about scapegoats in history. Gould's mother, Helen Vaughn Rue Gould, was a descendant of the French pirate Wonny La Rue and was very active in politics.

Gould's mother gave him an Erector Set of toy buildings when he was a child and encouraged him to build things. He would construct objects, take them apart, and then fix them. He and his brothers, David and Geoffrey, enjoyed taking clocks apart and then trying to reassemble them. Gould revered Thomas Alva Edison and dreamed of becoming an inventor.

Gould attended Scarsdale High School in Westchester County, New York. He then entered Union College in Schenectady, New York, where he was a member of Sigma Chi fraternity. Classes with Union College physics professor Frank Studer led to Gould's fascination with optics and the physics of light. In 1941, he received a bachelor of science degree in physics. He then did graduate work in optics and spectroscopy at Yale University and received an M.S. in physics in 1943. After graduating, Gould joined the Manhattan Project, which was focused on developing the atomic bomb. He worked on the separation of uranium isotopes to generate nuclear power. During this time, he met Glen Fulwider, a Marxist and colleague on the Manhattan Project. Gould joined her communist circle of friends. Because of their leftist leanings, Gould and Fulwider were fired from the project in 1945. They married in 1947, but the marriage eventually ended in 1953.

Life's Work

From 1947 to 1954, Gould taught physics at the City College of New York and worked for private engineering companies. In 1949, he enrolled in the graduate physics program at Columbia University, where he studied optics. In November, 1957, Gould conceived of the idea for a device that could shoot out a narrow, intense beam of light that could heat things to an extremely high temperature. He named this device a "laser," an acronym for "light amplification by stimulated emission of radiation." Gould recorded his ideas and sketches in a notebook, which he had notarized on November 13, 1957. However, Gould mistakenly believed that he could not file for a patent for his invention until he had submitted a working model.

He had discussions with physics professor Charles Hard Townes, who in 1953 had invented the maser (microwave amplification by stimulated emission of radiation), the laser's predecessor. They discussed Gould's research on using light to excite thallium atoms, and the idea of an optical version of the maser, which would use optical pumping instead of microwave amplification. The device would thus expand the principles of the maser to the shorter wavelengths of light.

Gould wanted to build the laser in 1958. Lacking the resources to do this, he approached Technical Research Group (TRG), a young Manhattan-based company that did contract work for the Pentagon. In March, 1958, Gould began work at TRG on a project to develop atomic clocks. He convinced TRG to build a laser, and the company sent a proposal to the Air Force Office of Scientific Research and the Army Signal Corps on December 16, 1958. Although TRG received a military contract, Gould could not get a security clearance to be part of the research team because of his association with Marxists in the 1940's.

On December 15, 1958, Townes and Arthur L. Schawlow, a researcher at Bell Laboratories, published the first scientific paper describing a laser, or optical maser, which would use infrared and/or visible-spectrum light. Gould officially filed an application for a patent in 1959. However, Townes and Schawlow had already filed patent applications for the laser, and Gould's application was denied.

On May 16, 1960, physicist Theodore Harold Maiman of Hughes Research Laboratories in California demonstrated the first working laser, the ruby laser, which produced bursts of red light. He had won the race to build the first working laser. Six months later, Ali Javan and his team demonstrated the first gas laser, the

Gordon Gould, inventor of the laser, in 1977. (AP/Wide World Photos)

helium-neon laser, which generated a continuous beam of light.

In 1967, Gould became a professor at the Polytechnic Institute of Brooklyn. In 1973, he left teaching to found Optelecom, a firm in Gaithersburg, Maryland, that specialized in fiber-optic communications equipment. In fiber-optic communications, information is transmitted by sending light through an optical fiber. Optelecom was a very lucrative business, and Gould retired in 1985.

Meanwhile, Gould had continued his patent war. He had received laser patents in Belgium in 1962 and in Great Britain in 1964, but his legal battle in the United States lasted three decades. Having lost many appeals, Gould's legal team tried a new strategy: focusing on the optical amplifier, an essential laser part. Consequently, in 1977 he won his first U.S. patent, which was for the optically pumped laser amplifiers. In 1978, the Patent Office Society named him inventor of the year for his laser amplifier. In July, 1979, he was awarded the second patent, which covered laser applications, including welding, drilling, measuring distance, photochemical processes, heating materials, and communication systems. However, court battles continued with companies disputing his patents and refusing to pay royalties.

In 1985, a U.S. district court ruled in favor of Gould's application for the discharge-excited laser patent, and Gould obtained two more patents. In November, 1987, he won the patent for collisionally pumped laser amplifiers, and his patent of May, 1988, covered the optical element inclined at a Brewster's angle. Gould and his assignee, Patlex Corporation, founded in 1979 to handle licensing and enforcement, now held four patents that covered most types of lasers and laser applications. These patents included the lasers used in 80 percent of commercial, medical, and industrial applications.

With the end of litigation in 1988, Gould began receiving royalties. Eighty percent of the proceeds went to cover his court costs, but Gould still eventually made tens of millions of dollars. By this time, lasers had universal applications and a global market, so the patents were worth much more than when Gould had begun the patent war. In recognition of his achievements, Gould was inducted into the National Inventors Hall of Fame in 1991. He died of natural causes on September 16, 2005.

THE LASER

Gordon Gould is credited with inventing the laser. He was the first person to envision the powerful laser beam and how to create it. The fundamental idea came from Albert Einstein's description of the relationship between matter and light. In 1916, Einstein proposed the idea that atoms, the basic building blocks of matter, could release excess energy as light, either spontaneously or when stimulated by light.

The laser consists of an optical resonator (laser cavity) between two mirrors, one fully reflecting mirror on one end and a partially reflecting one on the other end so that light can leak out. Light bounces back and forth between the two mirrors and is amplified by a gain medium (such as a crystal or gas) in the resonator. The gain medium is "pumped" by an external energy supply, such as light (optical pumping) or an electric current. The process of light amplification is called stimulated emission. In this process, a photon, the basic unit of electromagnetic energy (or light) excites an atom, which then releases a new photon identical to the incoming photon and going in the same direction. As photons excite more atoms, more photons get amplified. When enough atoms have jumped up into an excited state, then there is a population inversion, and laser light is created. Laser light is monochromatic and its waves are uniform, all going in the same direction and reinforcing each other, resulting in an intense beam.

Gould eventually won patents for the optically pumped and discharge-excited laser amplifiers now used in most industrial, commercial, and medical applications of lasers. Common types of lasers include solid-state lasers, gas lasers, and semiconductor lasers. Solid-state lasers use ion-doped crystals or glasses, pumped with discharge lamps or laser diodes. They include the ruby laser, used in holography and tattoo removal; and the high-power Nd:YAG (crystal) laser used in military range finders, dentistry, eye surgery, and manufacturing. Gas lasers are based on gases typically excited with electrical discharges. Examples include the helium-neon laser, used in bar-code scanning and holography; and the excimer laser, used in laser surgery and ultraviolet lithography. Semiconductor lasers are electrically or optically pumped. They include the most prevalent laser, the AIGaA, which is used in laser pointers, data communications, compact disc players, and optical discs. Another example is the semiconductor laser diode, whose applications include printing, welding, and telecommunications.

IMPACT

Gould is famous for his invention of the laser, giving the laser its name, and his ultimately successful thirty-year battle to win credit and patents for his invention. His well-documented struggle has continued to cause debate about U.S. patent law and procedures, competition among scientists and laboratories, simultaneous scientific discoveries, scientific awards, and royalties for inventions.

Gould had wanted to be an inventor since he was a child; so while other scientists were theoretical and analytical in their approach, Gould was intuitive and practical. In the race to build the laser, other scientists envisioned a light beam that could travel through air and be used as a research tool. Gould, on the other hand, was the first to conceive of an intense, narrow, and continuous beam of concentrated light that would be powerful enough to cut, drill, and weld. He envisioned a tool that could heat materials to ultra-high temperatures in a split second.

By the time Gould won his patent war, various kinds of lasers had been built that fulfilled his original vision and gave him millions of dollars in royalties. Lasers had become standard tools with widespread applications in medicine, manufacturing, research, communications, and technology. From the simple pointers used by lecturers to the range finders used in space probes, lasers had become ubiquitous. In the twenty-first century, examples of laser applications include cosmetic surgery, supermarket Universal Product Code (UPC) scanners, fiberoptic communication, vision correction, laser printers, compact disc (CD) audio players, CD-ROMs, vision correction, and digital video disc (DVD) technology.

—*Alice Myers*

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See also: Albert Einstein; Ali Javan; Theodore Harold Maiman; Arthur L. Schawlow; Charles Hard Townes.

MEREDITH C. GOURDINE

American engineer

Gourdine utilized his electrogasdynamics (EGD) knowledge to design generators to produce electricity from gas. His research and inventions benefited domestic, commercial, and industrial uses with such developments as devices that removed pollutants from air and heat from computer chips.

Born: September 26, 1929; Newark, New Jersey
Died: November 20, 1998; Houston, Texas
Also known as: Meredith Charles Gourdine (full name)
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Electrogasdynamic (EGD) generator; Incineraid; Electradyne paint spray gun

EARLY LIFE

Meredith C. Gourdine (gohr-DEEN), was born on September 26, 1929, in Newark, Jersey, to Albert and Charlotte (Carter) Gourdine. He lived with his paternal grandparents in Union, New Jersey, as an infant while his parents sought employment during the Depression. At age five, Gourdine resided in Harlem, New York, where his father became an apartment superintendent. He relocated to Brooklyn, New York, in 1940 when his father began working at the Brooklyn Navy Yard. Gourdine enrolled in Brooklyn Public School no. 67, where a mathematics teacher mentored him, explaining how to solve difficult problems. As a result, Gourdine's examination scores qualified him for admission to the prestigious Brooklyn Technical High School. Gourdine ran track and swam for school teams.

After graduation, Gourdine started classes at Cornell University in Ithaca, New York, in 1948, majoring in engineering physics. Known as "Flash" for his swiftness, he joined the Cornell track team, with the long jump, sprints, and low hurdles as his specialties, and won several Intercollegiate Association of Amateur Athletes of America titles. Gourdine helped Cornell's team achieve second place overall at the 1952 National Collegiate Athletic Association (NCAA) track meet. He competed in the 1952 Olympics in Helsinki, Finland, and was the long jump silver medalist, leaping 24 feet, 8.5 inches.

Prioritizing Olympic training, Gourdine did not concentrate sufficiently on his coursework and no longer qualified for his scholarship. He earned tuition funds assisting a campus research project, but the directing professor was unimpressed by Gourdine's work. Determined to prove his competence, Gourdine learned to balance his varied academic and extracurricular activities. He also participated in Cornell's Naval Reserve Officer Training Program. Gourdine completed a bachelor's degree in 1953. Commissioned as a U.S. Navy officer, he was deployed for two years on an aircraft carrier, gaining practical experiences with electronics. In 1955, he married June Cave. They later divorced, and he wed Carolina Baling. Gourdine had three daughters and one son.

LIFE'S WORK

Gourdine, dissatisfied with military work, decided to continue his engineering physics education by pursuing a doctorate. He enrolled in the California Institute of Technology in Pasadena, California, and received a Guggenheim Foundation graduate fellowship. Gourdine also financed his studies with a fellowship from the Ramo-Woolridge Corporation, for which he performed technical work in 1957 and 1958. Influenced by his adviser, Dr. Julian D. Cole, an applied mathematician, Gourdine researched mathematical aspects of magnetic fields and how objects' movement in those fields affected magnetic behavior, writing his dissertation "On Magnetohydrodynamic Flow Over Solids" to receive his Ph.D. in engineering science in 1960.

During his doctoral studies, Gourdine conducted research from 1958 to 1960 at the Jet Propulsion Laboratory in Southern California, where he investigated electrogasdynamics (EGD), the production of electricity from the conversion of kinetic energy in moving, ionized gas. Gourdine experimented with ways to manipulate EGD to create ample amounts of high-voltage electricity needed for industrial machinery and processes in addition to lighting and other basic functions. Frustrated when his supervisors did not appreciate his EGD insights, Gourdine sought a more compatible work environment. Starting in 1960, he directed an aerospace laboratory at Plasmadyne Corporation in Santa Ana, California, where he pursued earlier research he had begun exploring: magnetohydrodynamics as a method to produce power with gas and magnetic fields. Again, he was disappointed with his colleagues' reception of his work.

By 1962, Gourdine returned to New Jersey, where he was the Curtiss-Wright Corporation's chief scientist for aeronautics. During 1964, he invented an EGD channel for gas to move through to interact with electrodes to create charged particles (ions). Gourdine designed the channel's shape to compress ions to intensify forces affecting gases, increasing the amount of power produced. He was unsuccessful in convincing his company or others to develop his EGD generator. Unhappy with corporate restrictions and determined to protect his EGD ideas, Gourdine resigned from his Curtiss-Wright position, and, investing his money and approximately $200,000 in loans from friends, he started Gourdine Systems, Inc., in Livingston, New Jersey.

Gourdine's company, for which he served as president and chairman of the board, provided him autonomy to invent unique devices and technical processes through research and development projects he chose to pursue. His corporation made EGD generators, known as Gourdine Mark I, for school laboratories and licensed the boiler manufacturer Foster Wheeler Corporation to produce industrial EGD generators. In 1966, the U.S. Department of the Interior gave Gourdine $680,500 to create an EGD generator specifically to power a process to extract energy from coal. He filed for his first U.S. patent that year, receiving two EGD-related patents in June, 1969. In his home's basement, Gourdine maintained a laboratory for plasma physics experimentation to develop power supplies.

By 1974, Gourdine decided to cease work at Gourdine Systems and created Energy Innovations, located first in East Orange, New Jersey, then Houston, Texas. Serving as chief executive, Gourdine focused on his inventions. Throughout his career, Gourdine patented approximately seventy inventions with the U.S. and foreign patent offices as inventor or coinventor. His inventions included the Electradyne paint spray gun, which used EGD principles to give paint particles electrical charges, enabling users to coat paint over items of diverse shapes. Gourdine's Incineraid captured pollutants and smoke released from incinerators. Another device

ELECTROGASDYNAMIC METHOD AND APPARATUS

Meredith C. Gourdine utilized his engineering physics knowledge to research electrogasdynamics (EGD), which was the basis for many of his patents. His comprehension of the dynamic behavior of gases and ions enabled him to control them to produce enormous amounts of energy and manipulate particles by using electrical charges. Basic EGD concepts, the conversion of electrically charged flowing gas into energy while undergoing intense pressurization, had been described in scientific literature since the latter eighteenth century. Scientists, however, were unable to achieve conditions necessary to secure the energy potential of EGD with available scientific equipment. By the mid-twentieth century, Gourdine envisioned how he could create a device to place sufficient force on gases to produce energy and began to construct that technology. He designed his generator to exert tremendous pressure on gases moving though a narrow channel containing electrodes.

In the mid-1960's, Gourdine first applied for U.S. patents to document his EGD work and received two patents in June, 1969. Gourdine's initial approved patent, "Electrogasdynamic Method and Apparatus for Detecting the Properties of Particulate Matter Entrained in Gases," described a tubular device he created to evaluate particles in flowing gas. This patent was referenced in other patents for ion and particle sensors from the 1970's through the early twenty-first century. In his next patent, "Gourdine Electrogasdynamic Systems," Gourdine described a channel in which ionized gases were converted to electrical energy when passing through electrodes. Gourdine emphasized that his arrangement of electrodes conducting electrical charges in his generators were more effective than designs other scientists had presented. Several patents, including a 1980 discharge electrode structure and a 2006 electrostatic fluid accelerator, referenced this Gourdine patent.

Gourdine's early EGD patents formed the foundation of his later inventions, often consisting of improvements or design variations. "Electrogasdynamic Systems and Methods," which was approved as a patent in 1971, preceded Gourdine's prolific acquisition of EGD patents. Referring to other inventors' patents for electrostatic and ionization inventions, Gourdine refined his generator channels and source of electrical charges. During the 1970's, he received several patents for EGD coating inventions, mostly for electric forms of industrial painting. He continued that work in the next decade, while also investigating temperature regulation for electronics through the 1990's. Gourdine also applied his EGD methods to acoustic imaging and high-speed printing. He appropriated electrostatic precipitator techniques, inventing systems controlling unwanted particles with electric charges. Gourdine's EGD inventions performed essential roles in technological systems worldwide to provide reliable energy sources for daily electrical needs, to enhance industrial production, and to clean the air.

used electrical charges to remove dust. His focus flow heat sink cooled computer chips.

Gourdine aspired to improve his existing inventions with more research and development and expanded EGD techniques for automobile exhaust purification, salt removal from seawater, refrigeration, and other useful tasks. He licensed his inventions to companies, including Sherwin-Williams, and also arranged for representatives such as the Estey Corporation to produce and distribute technologies by Energy Innovations. Gourdine's corporation generated several million dollars from his patents.

Gourdine published technical articles in such periodicals as the *Journal of Fluid Mechanics* and *Industrial and Engineering Chemistry* and proceedings of conferences he attended sponsored by professional organizations and universities. He also prepared publications printed by the Society of Automotive Engineers, Plasmadyne, and military agencies. Gourdine's final research projects investigated converting thermal and chemical energy to electricity for technological applications, resulting in his last patents, which were issued in 1996.

Gourdine had become diabetic while serving in the Navy. He invented despite retinopathy affecting his eyesight, having a leg removed, and relying on dialysis treatments. By 1986, he was blind. On November 20, 1998, Gourdine, suffering strokes, died in Houston's St. Joseph Hospital.

Impact

Gourdine comprehended aspects of EGD to obtain energy through the conversion of gas into electricity, a complex process that had eluded scientists for several centuries, and achieved significant inventions incorporating that knowledge. His EGD research, which many peers described as pioneering, provided Gourdine and his businesses sizable profits and benefited industrial and commercial users of EGD technologies. Internationally, Gourdine's EGD generators affordably and conveniently created energy without harming the environment, with some inventions decreasing atmospheric pollution by removing contaminants. Officials in New Jersey approved statewide use of Gourdine's Incineraid. His EGD coating devices improved such industrial processes as painting products efficiently and economically. Gourdine's fog-removal system made runways safer and aided airlines by minimizing fog-related disruptions and related costs to compensate passengers. His method appealed to smaller airports, which often could not afford competitors' expensive methods using heat.

Gourdine's work attracted public attention, including from government officials who sought his expertise to shape policies. In 1964, U.S. president Lyndon B. Johnson appointed Gourdine to the federal Advisory Panel on Energy. President Richard M. Nixon selected Gourdine to serve on the President's Task Force on Improving the Prospects of Small Business. Gourdine also provided his insights for the U.S. Army Science Board and New York City Task Force on Air Pollution. Educational institutions valued Gourdine, naming him to the board of trustees at Cornell University and the New Jersey College of Medicine and Dentistry.

Gourdine contributed to advances in physics research by sharing his knowledge of EGD principles with other scientists and engineers. His achievements secured professional recognition. By 1964, Gourdine was an American Institute of Aeronautics and Astronautics associate fellow. An Industrial Research Award recognized the Gourdine Mark I generator. In 1969, Gourdine received honorary degrees from Newark State College and the New Jersey Institute of Technology. He was elected to the National Academy of Engineering in 1991 and inducted into the Engineering and Science Hall of Fame three years later. Gourdine also was selected for the Brooklyn Tech Alumni Hall of Fame in 1998 and the New Jersey Inventors Hall of Fame in 2004.

—Elizabeth D. Schafer

Further Reading

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"Energy at the Mine Mouth." *Time*, June 3, 1966, 42-43. Features the coal mine EGD generator Gourdine designed, which was funded by a government contract. Includes a photograph of Gourdine and details about his generator's operation.

Kahn, Bernard, and Meredith C. Gourdine. "Electrogasdynamic Power Generation." *AIAA Journal* 2, no. 8 (August, 1964): 1423-1427. Technical article Gourdine wrote with a Curtiss-Wright colleague that outlines early investigations testing theories to use EGD methods to produce energy. Photographs show generators. Diagrams, figures, and references supplement text.

Pierce, Ponchitta. "Science Pacemaker." *Ebony*, April, 1967, 52-54, 56, 58, 60-62. Contemporary essay about

Gourdine includes biographical details and discusses his company's achievements, early EGD inventions, and research goals. Photographs portray Gourdine, his family, and colleagues.

Sluby, Patricia Carter. *The Inventive Spirit of African Americans: Patented Ingenuity*. Westport, Conn.: Praeger, 2004. A patent agent discusses Gourdine's scientific background and technological achievements. Includes an illustration of his first EGD patent and lists twenty-eight of his patents in an appendix.

Spangenburg, Ray, and Kit Moser. *African Americans in Science, Math, and Invention*. New York: Facts On File, 2003. Profile includes quotations by Gourdine and notes highlights of his professional career, mentioning several of his EGD inventions.

See also: Frederick Gardner Cottrell; John Tyndall.

BETTE NESMITH GRAHAM

American typist

At a time when electric typewriters were new and difficult to use, Graham invented a solution used to paint over typing mistakes. The product, later known as Liquid Paper, would ease the job of secretaries worldwide.

Born: March 23, 1924; Dallas, Texas
Died: May 12, 1980; Dallas, Texas
Also known as: Bette Clair McMurray (birth name); Bette Nesmith
Primary field: Business management
Primary invention: Liquid Paper correction fluid

EARLY LIFE

Bette Nesmith Graham was born Bette Clair McMurray on March 23, 1924, in Dallas, Texas. She was the first child of Jesse and Christine McMurray. Her sister Yvonne was born two years later. The McMurray family lived in a middle-class community where Bette's father worked in the wholesale automobile industry and her mother was a businesswoman, an artist, and a singer. Christine's capable handling of career and family taught Bette that a woman could both work and raise a family. The influence of family who believed in women's rights and abilities was not limited to her mother. Bette's great-great-grandfather was John Darby, one of the cofounders of Wesleyan College in Macon, Georgia, the first college in the world to grant degrees to women.

As a child, Bette was strong-willed and difficult. She had a number of problems in school and eventually dropped out when she was seventeen years old. She would later earn a GED in place of a high school diploma. When she was eighteen, she married her high school sweetheart, Warren Audrey Nesmith. Nesmith was a National Guard member who, after two months of marriage, was called to serve in World War II following the bombing of Pearl Harbor. Bette found herself pregnant and alone at nineteen years old, and she gave birth to Robert Michael Nesmith on December 30, 1942, in Houston, Texas. When her husband returned from the war, he had changed, and the three-year marriage ended in divorce in 1946. Bette was left to raise Michael (later of Monkees fame) as a single working mother. In 1949, she moved to Dallas.

LIFE'S WORK

During the years immediately after her divorce, Bette Graham worked and attended night classes to earn her GED in order to support herself and her child. Though she desired a career in art, it was not a financial possibility, so she turned to secretarial work. Graham's career in Dallas began with a secretarial job at Texas Bank and Trust. By 1951, she had been promoted to executive secretary at the bank. During her time there, Graham started working with new IBM electric typewriters. These typewriters were both a blessing and a curse: Secretaries could type faster because the keys depressed more easily; however, the ink was difficult to erase, so mistakes meant retyping a whole document. Whereas erasers worked on the old-fashioned typewriter ink, the new ink smudged when it was erased. While she was doing holiday artwork on the bank's windows, Graham realized that artists cover errors with paint rather than erasing them. This led her to conclude that paint could cover typing errors as well.

Graham made a mixture of white, water-based tempera paint that she named Mistake Out, which she put in a container and brought to work. Using an artist's detail brush to apply the paint, she was able to cover her typing errors. If the stationery was not white, she simply tinted the paint to match the paper's color. Though her supervisors reportedly never noticed the typing repairs, Graham's secretarial colleagues did. When they eagerly asked to try the miracle solution, she shared.

Increasing interest from other typists inspired Graham to develop her correction fluid into a better product that she could market. By 1956, Graham had organized the Mistake Out Company and was using small appliances (a mixer and blender) in her kitchen laboratory to work out the best mixture. Her laboratory moved twice in these early days: once to the garage and then to a toolshed that she had purchased specifically to house the business. As she began to sell the mixture to more colleagues, she improved it with the help of a high school chemistry teacher and an assistant who had experience working in a paint manufacturing facility. Her son and his friends helped fill orders by filling and labeling bottles. Work was steady during her time away from her job at the bank, but she did not make financial leaps. When she absentmindedly put her new company's name on a business letter for work (she was by then working for IBM), her boss fired her for the error. This turned out to be a blessing, because it gave her time to dedicate herself to her fledgling company, and sales increased.

LIQUID PAPER

Before the invention of Liquid Paper by Bette Nesmith Graham, secretaries and other typists were confronted with a predicament: Though the new IBM electric typewriters were faster and easier to use than other models, mistakes made while typing on them often required redoing the work. Older, manual typewriters used ink that erased with a simple pencil eraser, but the new electronic typewriters used carbon ribbons, whose ink smudged when erased.

An artistic ability earned Graham part-time jobs painting holiday scenes on the windows of the bank where she worked. Realizing that artists cover errors with paint rather than erasing them, she concluded that paint could cover typing errors as well. Graham experimented with a water-based tempera paint mixture to fix typos. When the paint worked and her employers did not seem to notice the fix, she began to develop the product. She originally named it "Mistake Out," later renamed "Liquid Paper," and she used it regularly in her job as an executive secretary. The simple idea grew into a business when other secretaries started noticing and asked for their own bottles of correction fluid.

The product eased pressure on secretaries everywhere. They no longer needed to retype documents if they made a simple key error. They could simply paint over the mistake and move on to the next typing job. Hours, paper, and jobs were saved as typists were able to complete jobs in one attempt. Between 1956 and 1975, Graham's business boomed from a household laboratory with a handful of teenage employees filling bottles in the kitchen, garage, and toolshed of her home to a 35,000-square-foot factory that housed two hundred employees, a library, and a child-care facility. In 1979, Graham sold her business for about $48 million. A simple idea, a mixture of white paint and water, had become a multmillion-dollar enterprise.

Within the next eleven years, Graham's life would change both personally and professionally. Advertisement through an article in an office supply magazine generated five hundred orders in 1958. National corporations were starting to notice the product as well, and General Electric placed an order in excess of four hundred bottles. In 1962, Bette met and married Robert Graham, a salesman. Her new husband promptly joined the business, which was selling five thousand bottles per week by 1964. In 1968, she opened her own manufacturing facility and company headquarters, supporting nineteen employees. Her million-dollar company was now producing one million bottles per year. With the growth of the company, a new name, Liquid Paper, was born. By 1970, her company's production had increased to five million bottles per year. In 1975, a new facility was built in Dallas, and production again leapt, to five hundred bottles per minute. Bette Graham now employed two hundred people and marketed the product to dozens of countries. She also divorced her husband that year. In 1979, Gillette Corporation made an offer to purchase Liquid Paper, and Graham sold it for $47.5 million.

IMPACT

Graham's business revolutionized the work of secretaries worldwide. The simple act of painting over a typo instead of retyping a page saved a great amount of time and energy. The growth in popularity of her product also led to large numbers of employment opportunities.

Graham was able to develop her business while maintaining a positive relationship with her son. Understanding the difficulties of being a working mother, she even established an in-house child-care facility in the Dallas facility. She shared her wealth and experiences with her employees and others through family-friendly work environments and charities. Later in her life, she established the Bette Clair McMurray Foundation (1976) and the Gihon Foundation (1978) to offer aid to women in need and to further their efforts in the arts and business. The latter foundation's mission has been to encourage entrepreneurial philanthropy. Graham, a Christian Scientist, retired at age fifty-two to devote herself more fully to her practice.

—*Theresa L. Stowell*

Further Reading

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Vare, Ethlie Ann, and Greg Ptacek. *Women Inventors and Their Discoveries*. Minneapolis, Minn.: Oliver Press, 1993. The authors share a collection of biographical essays about female inventors. Their subjects range from Elizabeth Lucas Pinckney, who developed indigo dye, to Graham.

Waisman, Charlotte S., and Jill S. Tietjen. *Her Story: A Timeline of the Women Who Changed America*. New York: HarperCollins, 2008. A comprehensive discussion of women's contributions throughout U.S. history, from the sixteenth to the twenty-first century. Covers women such as Elizabeth Cady Stanton but also lesser-known women such as Graham. Includes a fascinating time line.

Ware, Susan, and Stacy Braukman, eds. *Notable American Women: A Biographical Dictionary–Completing the Twentieth Century*. Rev. ed. Cambridge, Mass.: Belknap Press, 2004. This comprehensive reference book covers progressive women whose death dates range from 1976 to 1999. Graham is discussed in regard to her business acumen and impact on women. Put together in association with Harvard University and the Radcliffe Institute for Advanced Study.

See also: William Seward Burroughs; Richard G. Drew; Lillian Evelyn Gilbreth; Charles Martin Hall; Beulah Louise Henry; Herman Hollerith; Margaret E. Knight; Arthur L. Schawlow.

ELISHA GRAY

American engineer

Gray was one of several people involved with the invention of the telephone. Because he filed a patent for the telephone on the same day as Alexander Graham Bell, there is no sure way to determine who had precedence and therefore who invented the telephone.

Born: August 2, 1835; Barnesville, Ohio
Died: January 21, 1901; Newtonville, Massachusetts
Primary fields: Communications; electronics and electrical engineering
Primary invention: Telephone

Early Life

Elisha Gray was not born with a silver spoon in his mouth, nor did he come from a line of engineers or scientists for whom inventing was second nature. He was, in fact, a farm boy who was also employed as a carpenter. Nevertheless, he understood that only through education could he achieve a life of value. Gray was born in Barnesville, Ohio, on August 2, 1835. His parents, David and Christiana Edgerton Gray, had moved there from western Pennsylvania and established a modest farm. Elisha attended grade school until his father died, when he had no alternative but to leave school and assist his widowed mother. Not long thereafter, she remarried to Cozens Smith, a Quaker farmer who lived in East Bethlehem, Pennsylvania, where the family moved.

Gray was apprenticed to a blacksmith, then a carpenter. Unsatisfied with his work, he enrolled in a high school whose principal was L. F. Parker, a recent arrival from Oberlin, Ohio. Gray worked early in the morning and late in the evening at his carpenter's job, attending school in midday. In 1856, he graduated from high school and enrolled in Oberlin College. Although he never graduated from Oberlin, he taught electricity and science there and built laboratory equipment for the science departments.

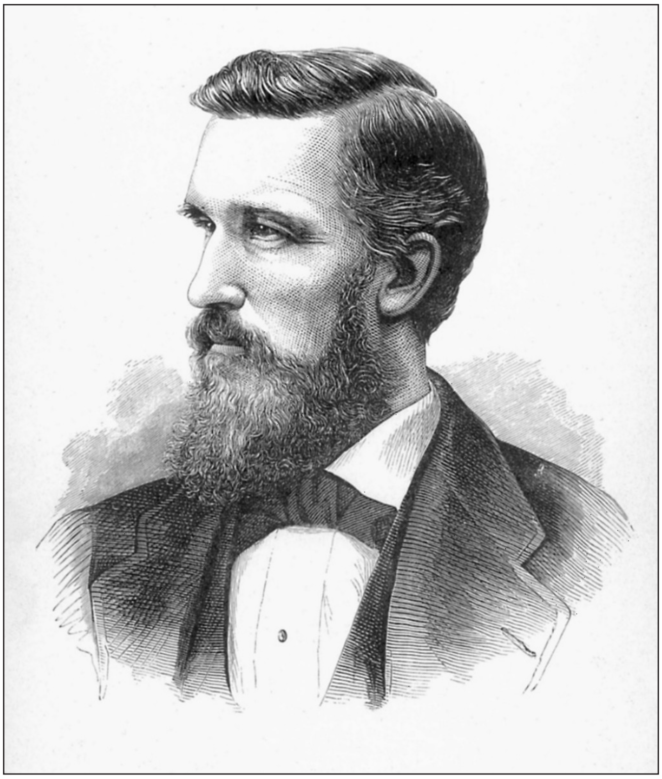
Life's Work

Gray is most often identified with an invention for which he did not receive a patent—the telephone. That patent was awarded to Alexander Graham Bell. However, there is debate as to who truly invented the device, and to this day there is no way to determine the details of the events of February 14, 1876, when both men filed for their patents. There were many lawsuits regarding the matter, all of which Bell won. (At one time, Gray congratulated Bell on the invention itself, leading some people to conclude that Bell had invented the telephone.) On that February day, Bell filed a patent entitled “Improvements in Telegraphy,” while Gray filed a caveat (an abbreviated patent) for a device “for transmitting vocal sounds telegraphically.” In all the discussions, arguments, and court battles that took place in the ensuing years, little differentiation was made between the two inventions.

Unlike a patent, which included drawings, description, and claims, a caveat included only drawings and description. The caveat was much less expensive to file and essentially stated that the filer had invented a particular device. If at some later date another similar invention appeared, the filer of the caveat had three months to take further action. At that time, actual dates of invention and practice could be compared. Because the patent and the caveat served essentially the same purpose, the question that arose in the Bell-Gray controversy was who had filed first.

The filing fee for Gray’s caveat was entered on the cash blotter hours after Bell’s filing fee; this evidence quite logically suggested that Bell was first. However, there were indications that the various filings that day were put in the in-box in sequential order and that the recording of the events was handled hours later. If this was the case, then Gray’s application was at the bottom of the in-box (first in, last out) and would mean that Gray preceded Bell. In addition, Gray was slow in taking any action to challenge Bell’s patent. This was likely due to opposition by Dr. Samuel S. White, Gray’s financial benefactor, to any work on the telephone. In late 1877, Gray applied for a patent for the same invention. This action put him in interference with Bell’s patent. The patent examiner held that “while Gray was undoubtedly the first to conceive of and disclose the [variable resistance] invention, as in his caveat of February 14, 1876, his failure to take any action amounting to completion until others had demonstrated the utility of the invention deprives him of the right to have it considered.”

Gray’s work on the telephone, though by far his most interesting effort, was not his only achievement. He was the recipient of more than seventy patents, most of which dealt with telegraphy. His first invention was a self-adjusting telegraph relay—a device that compensated for the electrical characteristics of different transmission lines. He received a patent for this device in 1867, nine years before the telephone patent controversy. An invention of particular note was the “telautograph,” a device that proved to be the predecessor of the fax machine. It was designed to remotely transmit handwriting through telegraph systems. Several patents pertaining to it were awarded to Gray. His effort resulted in the formation of the Gray National Telautograph Company in 1888; the company continued in business as the Telautograph Corporation until 1994, when it merged with a company that manufactured fax machines. Yet another invention was a primitive television system called the “telephote.” It used an array of selenium cells focused on a picture. Signals from these cells would be transmitted to a distant station on separate wires, and at the receiving end the signals would open or close a shutter to re-create the image.


Elisha Gray. (The Granger Collection, New York)

Gray’s corporate involvements also deserve note. For some years, Gray had been using a small shop in Cleveland for parts and models for his numerous experiments. He was so impressed with the work of the shop that he and his partner Enos Barton bought the company and labeled it Gray and Barton. Much of the work done by the organization was for Western Union, which invested in the manufacturing enterprise in 1872. Gray and Barton's company reorganized as Western Electric Manufacturing Company. In 1881, Western Electric joined the Bell System (named for the aforementioned inventor) after Bell purchased a controlling interest in its stock, and in 1882 Western Electric became Bell's exclusive manufacturer of telephone equipment in the United States. Thus, Elisha Gray became one of the founders of the Bell System's manufacturing facility—Western Electric.

In 1899, Gray moved to Boston, and on January 21, 1901, he died from a heart attack in Newtonville, Massachusetts. He is buried in Chicago's Rosehill Cemetery.

THE TELEPHONE

On February 14, 1876, Elisha Gray filed a caveat with the U.S. Patent Office, the opening paragraphs of which read as follows: "It is the object of my invention to transmit the tones of the human voice through a telegraphic circuit, and reproduce them at the receiving end of the line, so that actual conversations can be carried on by persons at long distances apart." It had been demonstrated previously that if the current in a wire could be made to vary, this variance could be translated into the mechanical vibration of some sort of membrane. This vibration could cause air molecules to vibrate, and this, by definition, is sound.

The question arose, how might one cause a human voice to control the current in a wire? Gray had the solution—one that was much better than that of Alexander Graham Bell. Gray stretched a thin diaphragm across a frame and attached a thin metal rod to the center of the diaphragm. This rod was dipped in a vat of acidulated water. Gray knew that this water was neither an excellent insulator nor an excellent conductor. He determined that if one millimeter of the solution had an electrical resistance of 100 ohms, then two millimeters would have a resistance of 200 ohms. He laid a conducting plate on the bottom of the vat and suspended the rod only a few millimeters from the bottom. The electrical circuit would be connected from a battery, to the rod, through the water, to the metal plate, and then to the long-distance circuit. A speaker, talking directly into the diaphragm, would cause the rod to vibrate up and down; this would cause the resistance to the transmission circuit to vary, and the human voice could be replicated at the distance telephone.

In later years, it was this transmitter that received the most attention. Something practical had to be designed for commercial and residential use. A number of inventors worked on this problem, and the person who was most successful was Thomas Alva Edison. Instead of the vat of acidulated water, Edison used a small capsule of granulated carbon. He had determined that this carbon, when pressed and released by a speaker's voice on the wall of the capsule, would cause the resistance to vary. This carbon transmitter became the standard of the industry and was used until the electronic telephone came into vogue.

IMPACT

The telephone invented by Gray was based on the variable-resistance principle—a theory that led to practical, commercial development of the invention. By the end of 1880, there were nearly fifty thousand telephones in the United States. These were connected to each other through what are today called "central offices." The first of these central offices, housing a huge switchboard, was established in New Haven, Connecticut, in 1878—two years after the invention of the telephone. These were manual switchboards controlled by operators who connected one telephone to another using a series of plugs and cords. This process was automated in 1891 by an undertaker, Almon Brown Strowger. The telephone network of today is ubiquitous, and it has grown from a wire-line network to a wireless network that carries voice, data, and video. It is able to connect people everywhere and is truly distance-independent.

Just as the telephone invented by Elisha Gray was an immensely important invention, so too was the commercial enterprise that capitalized on it—Western Electric. This company became the manufacturing facility of the largest telecommunications organization in the country—the Bell System.

—*Robert E. Stoffels*

FURTHER READING

Bigelow, Stephen, Joseph Carr, and Steve Winder. *Understanding Telephone Electronics*. 4th ed. Boston: Newnes, 2001. Discusses the trends and advances of the telecommunications field, with chapters on fiber optics, the Internet, and wireless communications.

Brooks, John. *Telephone: The First Hundred Years*. New York: Harper & Row, 1975. This seminal book on the early days of the telephone was commissioned by the Bell System and therefore is somewhat biased. It mentions, but does not emphasize, the role played by the independent telephone companies in the United States. An important book for the student of the telecommunications industry.

Evenson, A. Edward. *The Telephone Patent Conspiracy of 1876: The Elisha Gray-Alexander Bell Controversy and Its Many Players*. Jefferson, N.C.: McFarland, 2000. A detailed analysis that challenges the invention of the telephone by Alexander Graham Bell.

Pleasance, Charles A. *The Spirit of Independent Telephony*. Johnson City, Tenn.: Independent Telephone Books, 1989. Emphasizes the independent telephone industry, discussing not only the inventions and technical developments of the industry but also the strategy employed by the players—both Bell and others.

See also: Alexander Graham Bell; Emile Berliner; Thomas Alva Edison.

WILSON GREATBATCH

American medical researcher

Greatbatch developed and campaigned for the use of an implantable heart pacemaker. When he discovered that the power supply was causing pacemakers to fail, he developed a corrosion-free lithium-iodide battery that made the pacemaker a long-term possibility. This combination has saved millions of lives.

Born: September 6, 1919; Buffalo, New York
Primary fields: Electronics and electrical engineering; medicine and medical technology
Primary inventions: Lithium-iodide battery; implantable pacemaker

EARLY LIFE

Electricity and electronics always fascinated Wilson Greatbatch. In his early teens, he wound his own coil and built a two-tube shortwave radio, which allowed him to “visit” other places and people. The hobby was a blessing for Greatbatch, who was an only child. He also joined the Boy Scouts and later the Sea Scouts. During the aftermath of the 1938 hurricane that devastated New England, Greatbatch and the other Sea Scouts forwarded messages for twenty-six hours. The Red Cross gave them a citation for their work.

Greatbatch joined the Naval Reserve in 1938, and in 1940 his unit was called up for a year of service, which, however, extended through the end of World War II. He did many jobs during his service time, including operating a radio on a convoy ship, repairing electronic equipment, teaching in a radar school, and flying as a rear gunner in a dive bomber in combat. A third of his squadron perished in combat.

After the war, Greatbatch moved with his new bride, Eleanor, to his hometown of Buffalo, New York. He worked for the New York Telephone Company as an installer-repairman. After a year, he decided to attend Cornell University using his G.I. Bill benefits. Cornell did not have housing for him as a nonresident student, so he solved the problem by buying a nearby plot of land and enrolling as a resident student. He earned a bachelor’s degree in electrical engineering from Cornell in 1950 and a master’s degree in electrical engineering from the University of Buffalo in 1957. Cornell stressed a wide range of courses, especially in mathematics, physics, and chemistry, which helped prepare him for his career.

Wilson Greatbatch at his workshop in 1997. (AP/Wide World Photos)

Greatbatch worked several jobs to support his wife and three children. He ran the university radio station on weekends. He also built amplifiers that were later used in the Arecibo radio telescope in Puerto Rico. While working at the Psychology Department's Animal Behavior Farm, he met two doctors who explained heart block, a condition in which electrical impulses cannot properly travel through the heart, resulting in irregular heartbeats. Greatbatch thought he could fix this condition with the right equipment. From 1952 to 1953, he worked at the Cornell Aeronautical Laboratory, where he was involved in monitoring the physiology of the monkeys sent into space by the Army. From 1953 to 1957, he was assistant professor at the University of Buffalo School of Electrical Engineering. Greatbatch and his wife finally had five children, four of whom were boys.

LIFE'S WORK

While at the University of Buffalo, Greatbatch began to do work for the Chronic Disease Research Institute. One project involved recording heart sounds. While building an oscillator that would produce a constant electrical signal, Greatbatch picked up the wrong size resistor. The device repeatedly produced a short pulse, much like the beating of a heart. Greatbatch remembered his discussions with the doctors at the Animal Behavior Farm and realized that this device could be used to treat heart block, a condition that leads to a slowed heartbeat or to asystole, the absence of a heartbeat.

In 1957, Greatbatch became a division manager at Taber Instrument Corporation in North Tonawonda, New York. In 1958, he approached Dr. William Chardack, chief of surgery at the Veteran's Administration Hospital in Buffalo, about the concept of an implantable pacemaker. At the time, heart block was treated with a large suitcase-size unit outside the body. The treatment was painful and caused skin damage. Chardack's enthusiasm for the pacemaker concept moved Greatbatch to quit his job, and, using his savings of $2,000, he built fifty pacemakers in two years in his barn. The first pacemaker was implanted in a dog in May, 1958. A high school classmate of Greatbatch, Dr. Andrew Gage, joined Greatbatch and Chardack. By April 7, 1960, a human patient had lived with a pacemaker pacing his heart for one continuous year. Ten of the pacemakers went into human patients; the remaining devices were used in animal studies.

The pacemaker as developed by Greatbatch used two transistors and a transformer arranged in the style called a coupled blocking oscillator. It was encapsulated in epoxy resin and attached to electrodes that were attached to the patient's heart myocardium. The pacemaker was li-

THE LITHIUM-IODIDE BATTERY

Many people feel that the development of the lithium battery is more important than the development of the artificial pacemaker, which others had been working on before Wilson Greatbatch invented his device. Early pacemakers used mercuric oxide-zinc batteries, which had serious faults. First, the battery produced a small amount of hydrogen gas, which the body had to absorb. Second, it was necessary to separate the components with a fabricated separator. Third, the battery could not be hermetically sealed, because one of the reactions produced hydrogen gas. Because the battery could not be sealed, the pacemaker could not be sealed. Since the pacemaker was not sealed, the inside was often 100 percent humidity, which was a poor environment for electronic components. Moreover, the battery was capable of sudden failure, and its longevity was only one to five years.

Greatbatch introduced a lithium-iodide battery for the pacemaker in the early 1970's, and it soon became the standard power source in the world's pacemakers. It produces no hydrogen gas and therefore can be hermetically sealed. With a sealed battery, the pacemaker can be sealed, and leakage into the pacemaker is kept to a minimum. In the lithium-iodide battery, there is no fabricated separator that can fail; thus, the three main problems with the mercuric oxide-zinc battery were solved with the lithium-iodide battery.

The lithium-iodide battery produces a high voltage, 2.8 volts. However, because it has a large internal impedance, the maximum current is only one-tenth of a milliamp. That amount of current is too low for most uses, although it is fine for a pacemaker. The lithium is used as the anode. The cathode is a composite of iodine and poly(2-vinylpyridine). Neither solid iodine nor poly(2-vinylpyridine) are conductive. However, when mixed and heated, they form a conducting liquid that can be poured into the cell in which it forms a solid. When the solid touches the lithium anode, it forms a semiconducting layer of crystalline lithium iodide that is one molecule thick. This layer grows as the cell is discharged. The voltage of the battery changes with the thickness of the layer because the layer is resistive. This allows the battery to be tested without having to be removed from the body. The lithium-iodide battery thus allows for long-term use of a pacemaker. It is now the standard battery for pacemakers because of its small size, high voltage, low self-discharge, and reliability.

censed to Medtronic in Minneapolis. The medical world began to accept and use the pacemaker, partly because of the outstanding reputation of Chardack. In the first year, Medtronic made 300 pacemakers. By the year 2000, more than 600,000 were implanted worldwide annually.

In the first ten years of use, the lifetime of the pacemaker was about one and a half to two years. About 80 percent of the failures of the pacemakers were the result of battery failure. The mercury battery, which used mercuric oxide-zinc cells, could not be hermetically sealed because of the hydrogen gas given off by the reaction of the battery. Potassium hydroxide from the battery could leak out and destroy the circuitry, or the battery could fail because of the contaminants that leaked into the battery. Greatbatch replaced the mercury battery with a sealed, corrosion-free, lithium-iodide battery. This made the pacemaker a long-lasting solution to the problem of heart block and other cardiac conditions.

Greatbatch had formed Wilson Greatbatch, Inc., in 1960. This corporation dissolved in 1963, when Mennen-Greatbatch Electronics, Inc., was formed. Mennen-Greatbatch Electronics later sold its patents to Medtronic and dissolved. Wilson Greatbatch, Ltd., was formed in 1964 to sell medical electronic equipment in Eastern European countries. In 1985, Greatbatch Gen-Aid was formed to provide assistance in genetic engineering to the fields of medicine and agriculture. Between 1980 and 2000, Greatbatch worked with John Sanford of Cornell on inhibiting the replication of acquired immunodeficiency syndrome (AIDS) and another viruses in cats. He holds more than 220 patents.

Greatbatch has been generous with his good fortune, donating funds to Houghton College in New York for a graduate program in music and providing free tuition and books for his company's employees and their children should they wish to go to school. He also spends part of his time giving lectures and demonstrations.

IMPACT

When Chardack was first approached by Greatbatch, Chardack stated that an implantable pacemaker could save ten thousand lives each year. Today there are more than sixty times that number of pacemakers installed worldwide each year. Patients with heart block will often suffer syncope (loss of consciousness), and then can die. The pacemaker maintains normal blood flow and prevents heart block. The pacemaker also treats rapid and irregular heartbeat. An episode of irregular heartbeat can produce such a small flow of blood that immediate death can result.

Not only does the pacemaker save lives, but it also improves quality of life. A person with restricted blood flow is less able to think quickly or have the energy to do all the things that he or she wants to do. With the pacemaker, the heart produces an adequate flow of blood, which produces more energy and the ability to think quickly. People have lived thirty or more years with a pacemaker.

Greatbatch built upon the ideas of other inventors, but his persistence in getting a doctor to implant his pacemaker, first in animals and then in human patients, set him apart from other inventors and made the pacemaker a common treatment for cardiac problems. He also persevered in making a device that was long-lasting. He continually tested components, finally developing a corrosion-free battery that improved the longevity of both his device and the patients using it.

—*C. Alton Hassell*

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See also: Otis Boykin; John Alexander Hopps; Lewis Urry.

JAMES GREGORY

Scottish mathematician and astronomer

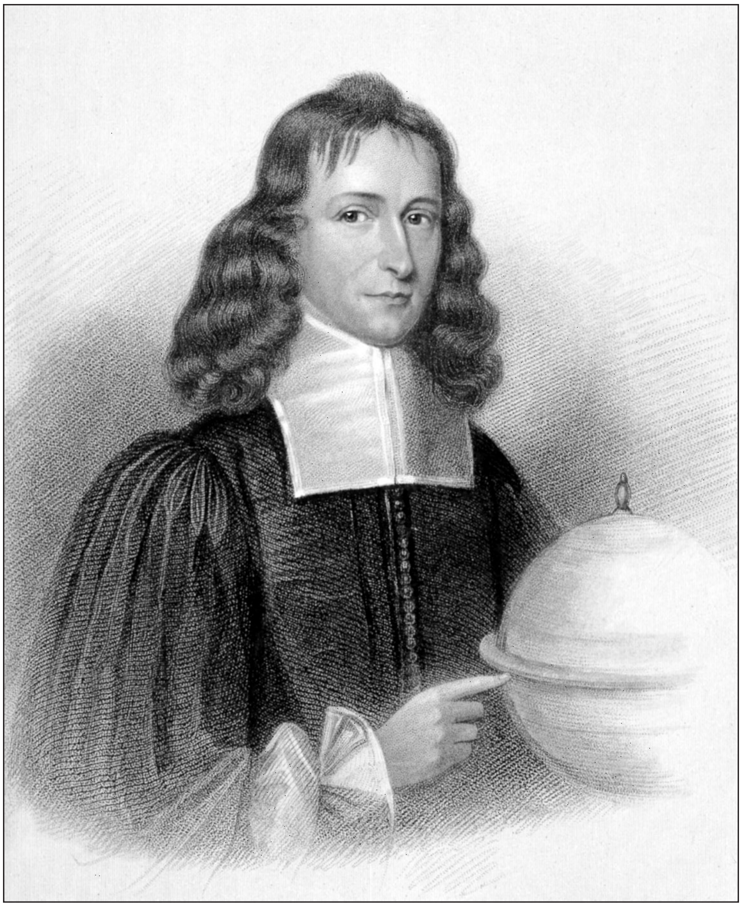
Gregory designed the first practical reflecting telescope. His design remains one of the most important type of optics used in telescopes, especially in large solar telescopes.

Born: November, 1638; Drumoak, Aberdeenshire, Scotland
Died: October, 1675; Edinburgh, Scotland
Also known as: James Gregorie
Primary fields: Astronomy; mathematics; optics
Primary invention: Gregorian telescope

EARLY LIFE

James Gregory was born in Drumoak, Scotland, in November of 1638; he was the third child of John Gregory, a pastor, and Janet Anderson. Gregory had two brothers: Alexander, the eldest, and David, who was ten years older than James. His mother introduced him to mathematics at a very young age, teaching him geometry. In 1651, when he was thirteen years old, his father died. His brother David took responsibility for his education and introduced him to Euclid's *Elements*, which James found simple and enjoyable to read. He also attended grammar school and studied in Aberdeen at Marischal College, the school where his father had studied.

Soon, Gregory began to study optics and telescope construction. Encouraged in his investigation by his brother David, he wrote *Optica promota* (1663), in which he described what would become known as the Gregorian telescope. Lacking the skills to construct the telescope, Gregory was unable at the time to proceed past the theoretical stage with his telescope.



James Gregory. (The Granger Collection, New York)

LIFE'S WORK

In 1663, Gregory went to London, where he met John Collins, who would become his lifelong friend and adviser. Gregory had moved to London for two reasons: He wanted to publish *Optica promota* (the advance of optics), and he wanted to find someone to construct the telescope described in his book. Several scientists were highly impressed by Gregory's book, including Oxford physicist Robert Hooke, who would build Gregory's telescope some ten years later; Robert Moray, a founding member and president of the Royal Society; and Sir Isaac Newton. Upon the advice of Collins, Gregory contacted a prominent optician named Reive and asked him to construct a parabolic mirror for the telescope. Reive accepted, but his work fell short of Gregory's expectations.

In 1664, Gregory left London and went to Italy, where he spent most of his time at the University of Padua working in mathematics. He concentrated his efforts on using infinite convergent series to find the areas of the circle and the hyperbola. He wrote two books during his stay in Padua. In 1667, he published *Vera circuli et hyperbola quadratura* and in 1668 *Geometriae pars universalis*, which was the first attempt to write a textbook on calculus.

Upon returning to London in the spring of 1668, Gregory sent a copy of *Vera circuli et hyperbola quadratura* to Christiaan Huygens, a highly respected Dutch mathematician, with a letter asking for his opinion on the work. Instead of personally replying to Gregory, Huygens published a highly critical review of the work in which he objected to a number of Gregory's conclusions and also stated that he had already expounded much of the theory for which Gregory was taking the credit. Gregory was severely upset by Huygens's review and subsequently was extremely reticent about his work. He rarely made public the methods that he used in his mathematical investigations.

Although Gregory was disappointed by Huygens's response to his book, his stay in London proved profitable for him. His friend Collins was well informed about the discoveries that were being made in mathematics and shared his knowledge with Gregory. Gregory also renewed acquaintance with his friend Robert Moray and attended the Royal Society's meetings. On June 11, Gregory was elected as a fellow of the prestigious society. He presented several papers to the society, including ones on mechanics, gravitation, and astronomy. He also published *Exercitationes geometricae*, which elucidated his knowledge of sine, cosine, and tangent. The work also served as a rebuttal to Huygens.

It is believed that it was Moray who convinced Charles II to establish the Regius Chair at the University of St. Andrews in order to enable Gregory to continue his mathematical research. Unlike the other professors at St. Andrews, Gregory was not assigned to a college. When he arrived there late in 1668, he was given the Upper Hall of the library as his work area. He gave two lectures each week. The faculty and student body of St. Andrews still adhered to a traditional view of mathematics and were totally uninformed about the latest developments in the discipline; therefore, Gregory's lectures were not well received. Shortly after his arrival at the university, Gregory met Mary Jamesome. They married and had two daughters and a son.

Gregory remained at St. Andrews for six years. During this time, he continued his work in both mathematics and astronomy. He kept abreast of other scholars' work through his correspondence with Collins. Gregory made significant discoveries that he shared with Collins but

THE GREGORIAN TELESCOPE

The Gregorian telescope is an example of a reflecting telescope. This type of telescope uses either a curved mirror or a combination of curved mirrors to reflect light and form an image. In 1616, Italian astronomer Niccolò Zucchi constructed the first reflecting telescope. In 1630, he used it to observe two bands on Jupiter and in 1640 to observe spots on Mars. However, the telescope had serious flaws that made it difficult to use. Zucchi did not succeed in accurately shaping the concave mirror. In addition, he was unable to find a way of viewing an image without blocking the mirror. Consequently, his telescope lacked practicality and did not become popular with astronomers.

In 1663, James Gregory published *Optica promota* (the advance of optics), in which he presented a design for a type of reflecting telescope. Some ten years later, the first Gregorian telescope was actually constructed by Robert Hooke. The telescope proved to be a good instrument for both astronomical and terrestrial observation. However, Sir Isaac Newton also designed a reflecting telescope and actually constructed one in 1668, a few years before the first Gregorian telescope was made. Thus, Gregory is usually credited with designing the first practical reflecting telescope, while Newton is credited with building the first practical reflecting telescope.

The Gregorian telescope uses two concave mirrors, a primary and a secondary mirror. The primary mirror is a concave paraboloid that collects the light and causes it to focus before the secondary mirror, which is a concave ellipsoid. From the secondary mirror, the light is reflected back through a hole in the center of the primary mirror. From there, the image is viewed with an eyepiece at the rear of the primary. The image produced by the telescope is upright. Thus, the Gregorian telescope is very practical for terrestrial observation.

The Gregorian telescope has a distinct advantage over the Newtonian telescope in that its design requires a shorter tube for the same focal length. However, the Cassegrain telescope (named for Laurent Cassegrain) is much more popular today than either the Newtonian or the Gregorian.

Nevertheless, the Gregorian design continues to be used for solar telescopes such as the Solar Optical Telescope on the Hinode satellite. Because the primary mirror creates an actual image before the secondary mirror, a field stop may be placed at this point, preventing light from outside the field of view from reaching the secondary mirror, thus reducing the amount of heat reaching the secondary mirror. In addition, Gregory's design and optics are found in many large telescopes, including the Vatican Advanced Technology Telescope and the Giant Magellan Telescope.

vacillated about publishing. Collins informed him that Newton had come to similar conclusions. Because of his respect for Newton and his desire not to repeat the Huygens incident, Gregory decided to wait for Newton to publish his findings.

Gregory set up his telescope in the Upper Hall of the library, but he tried unsuccessfully to establish an observatory at St. Andrews. The university permitted him to buy some instruments for the observatory but refused to fund the building of the observatory. Having been told that he would have to raise funds to construct it, Gregory traveled back to his home in Aberdeen to secure financial backing.

In 1674, Gregory became part of a collaborative project with his Parisian colleagues. They made simultaneous observations of an eclipse of the Moon. Despite his work, Gregory continued to be victimized by prejudice at St. Andrews. In 1674, he left the institution to take a position at Edinburgh University, where he was the first person to hold the chair in mathematics. There he continued his research in both mathematics and astronomy. He spent a considerable amount of his time attempting to solve quintic equations algebraically. Unfortunately, scarcely one year after going to Edinburgh, Gregory was suddenly stricken and blinded by a stroke while showing the moons of Jupiter to his students. A few days later, he died. He was thirty-six years old. Two lunar features are named after Gregory—the Crater Gregory and the Catena Gregory. His telescope design is known as the Gregorian telescope.

IMPACT

Because of his reluctance to publish the results of his research, Gregory did not significantly affect the development of the discipline of mathematics during his lifetime. Although he had actually discovered many formulas and solved many problems in mathematics before those credited with their discovery and solutions had done so, Gregory was not recognized for his work simply because he refused to make it known to either the scientific community or the general public. The majority of his investigations and discoveries remained unknown until the 1930's, when a scholar examined his papers, which had been preserved in the library at St. Andrews.

However, his design for a reflecting telescope, which he published in his book *Optica promota*, has been used in the making of telescopes since Robert Hooke, a friend of Gregory and an experimental scientist, constructed the first telescope using Gregory's design in 1673. Gregory's telescope was the standard one used for observations for a century and a half. The Gregorian telescope is still used today.

—*Shawncey Webb*

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See also: Robert Hooke; Christiaan Huygens; Zacharias Janssen; Sir Isaac Newton.

ALFRED J. GROSS

Canadian American engineer

Gross developed the concepts and basic workings of many modern electronic devices, including the walkie-talkie and the pager. His visionary work led to the mass communications systems that exist today.

Born: February 22, 1918; Toronto, Ontario, Canada
Died: December 21, 2000; Sun City, Arizona
Also known as: Irving J. Gross
Primary fields: Communications; electronics and electrical engineering
Primary inventions: Walkie-talkie; pager; radio tuner

EARLY LIFE

Alfred J. Gross was born in Toronto, Canada, but his family moved to Cleveland, Ohio, when he was an infant. When Gross was nine, his family was traversing Lake Erie on a steamboat when he discovered the ship's radio transmission station as he explored the vessel. The radio operator permitted Gross to observe as he received and transmitted messages to distant stations, and Gross's interest in wireless communication was sparked. He began tinkering with radios while still a young boy, dismantling and assembling them to learn their inner workings. By the time he was twelve, Gross had not only learned all there was to know about radio receivers but also built his first radio transmitter in his parent's basement. Radio was still a new technology, and Gross's transmitter, although homemade from mismatched parts, was one of the earliest and most powerful transmitters in the Cleveland area. As other radio enthusiasts began broadcasting on their own transmitters, amateur radio became more and more regulated. By the time he was sixteen, Gross had obtained an operating license for his transmitter, established a call sign, and joined the growing ranks of ham radio operators.

Two years later, in 1936, Gross enrolled in the electrical engineering program at Cleveland's Case School of Applied Sciences (now part of Case Western Reserve University). He excelled in the technical and theoretical aspects of radio technology and was soon making contributions of his own. Working with state-of-the-art equipment, Gross soon moved beyond his meager homemade radio. Radio sets of the time operated in a low-power setting below 100 megahertz (MHz). Because additional power meant that radio transmission could be heard more clearly at longer distances, Gross began to look for methods of harnessing additional power to radio transmitters. At the same time, he also realized that more power meant more weight, and so radio risked remaining as immobile as his large transmitter at home. Therefore, while searching for additional transmitting power, Gross also sought to make radio more portable.

LIFE'S WORK

Gross made his first great technical breakthrough in 1938, when he invented a powerful handheld transceiver using recent breakthroughs in battery technology and new lightweight vacuum tubes. The two-way radio device sent messages clearly because it operated in frequencies in the 200-300 MHz range rather than the usual 100 MHz. These upper ranges of the frequency scale became known as very high frequency (VHF) and ultrahigh frequency (UHF), which were generally allocated to television transmissions. Gross called his device a "walkie-talkie" because the transceiver allowed someone to move around while sending messages without remaining tied to a bulky transmitter.

With World War II raging in Europe, the Office of Strategic Services (OSS, the predecessor to the Central Intelligence Agency), the body responsible for conducting American intelligence operations during the war, took a keen interest in the walkie-talkie. The mobile radio was ideal for use by spies, who needed to be secretive yet able to relay information. Gross was recruited by the OSS to help develop a two-way communications system for the military; the ground unit was code-named "Joan," and the air unit, "Eleanor." Joan, officially the SSTC-502 transceiver, was a small but powerful device that weighed only four pounds and operated at 260 MHz. It permitted intelligence agents to relay information to overhead planes equipped with the Eleanor unit, the SSTR-6 transceiver. The Joan-Eleanor system was the first example of directional transmission. Unlike traditional transmitters, whose signals emanate from the antenna in all directions, the Joan-Eleanor system transmitted the message only upward to the airplane overhead. This allowed only the receiver in the airplane to hear the message; enemy eavesdropping was not possible. An added benefit was that the agent using the Joan device did not have to encode the message and could instead broadcast it in plain language. Encoding and decoding messages took time, but agents broadcasting messages in plain language could get their message across much faster and without any possible misinterpretation by the

Gross's Radio Tuner

The key piece of technology invented by Alfred J. Gross that made his citizens' band (CB) radio possible was his radio-tuning apparatus, which he patented in 1950. Gross's radio tuner was much more efficient than earlier tuners because it compensated for the tighter frequency bands available to CB radios.

Earlier radios required a separate tuning device attached to the radio receiver-transmitter. Because the tuning device was not an integral part of the radio, the mechanism was often unreliable and incapable of adapting if the transmission pattern changed. If an outside influence affected the incoming or outgoing transmission, the operator had to constantly adjust the tuner while trying to relay or receive the message. A change in either the broadcaster or receiver's location, for instance, meant that both parties had to retune their radios. This made radio transmission difficult from a moving vehicle. Gross's tuner, on the other hand, was an integral part of the radio. His "loop tuner" used the incoming electrical impulse of the message to reset the tuner automatically. With this system, someone using a CB radio did not have to constantly tune the radio after he or she set the original frequency. This made the radio much easier to use, especially for operators who had no previous experience. It also made the radio more hands-free: An operator could use a CB radio with one hand, pushing a button to transmit and releasing the button to receive. This made the radio much safer to use in trucks and vehicles that required attention while operating.

The functionality of the automatic tuner made the CB radio a life-saving device. For operators who might be in danger, the CB radio was simple enough for a novice user or someone under duress to use easily. Conversely, rescue personnel could communicate through their CB radios in real time to those who needed their help, a simple act that facilitated emergency assistance. Moreover, because those who needed help and their rescuers were using the same frequency band, communications device, and open airwaves, everyone associated with an emergency call could speak to one another without an intermediary, in contrast to a telephone, which required a coordinating operator and which allowed only one person to speak at a time.

receiver. The Germans were unaware that the Allies possessed a system that could operate in the VHF frequencies, so the Germans lacked a means to locate the Joan transceiver when it was operating. Consequently, OSS agents could use the device with little fear of detection. The government did not declassify the documents relating to the Joan-Eleanor system until 1976.

After World War II, Gross turned his wartime achievements to peacetime purposes. The Federal Communications Commission (FCC), the government agency responsible for managing commercial radio transmission, permitted private transmitters to operate in the VHF and UHF frequencies. The FCC established the Citizens' Radio Service Frequency Band (a "band" is a range of frequencies reserved for a specific purpose) in 1946 for the exclusive use of nonmilitary and nongovernment transmitters. With citizens' band (CB) radio, common Americans could now transmit personal messages on the higher frequencies, ensuring longer-range and clearer transmission than that of the much larger, bulkier, and more expensive transmitters of only a few years earlier. Gross established a company in Cleveland, Gross Electronics, Inc., in 1948 to manufacture transmitters in the citizens' band. Because of his expertise, his company was the first to receive FCC approval. Gross's CB radios soon became the most reliable means to communicate for people in remote areas or in occupations that required constant motion. Farmers came to rely on them, and CB radios soon equipped trucks that crossed the country delivering freight. Law-enforcement and rescue agencies also employed CB radios as an inexpensive and reliable means to serve the public and save lives.

Gross next turned his mind to inventing devices for long-distance, personal communications. In 1949, he demonstrated "remote telephonic signaling" with a pocket-sized wireless device known as the pager. Gross saw it as a life-saving device, capable of summoning help by sending an electronic summons if someone could not speak. Doctors and rescue workers did not like to constantly carry the summons device, so the pager did not immediately become popular. Gross's idea for the mobile telephone was also rebuffed. Gross envisioned the possibility of adapting the Joan-Eleanor system to personal use, proposing a modified walkie-talkie that used a directional antenna like that of the Joan unit. It could broadcast a voice message to a local receiver, which would in turn boost the power of the message and send it to the next receiver. Gross's new phone would be both cordless and mobile, and it was based on the same principle that modern cellular phones use. Unfortunately, Gross could not get anyone to pay attention to the idea. At the time, the Bell Telephone Company had a monopoly on the telephone industry; it was not going to allow its dominance to end because of wireless transmissions, so it discouraged Gross from pursuing the idea.

According to legend, Gross also influenced pop culture. Chester Gould, the creator of the *Dick Tracy* comics, claimed that Gross once showed him a proposed portable radio small enough to fit onto a wristwatch. Gould was so enamored with the possibilities of the device that he asked Gross if he could use it in his comic strip, and from 1946 onward Dick Tracy kept in contact with his fellow police officers through his Gross-inspired wrist radio. Gross continued to tinker with new ideas for the rest of his life until his death in 2000.

IMPACT

Gross saw the need for modern communications long before anyone else did. Although he invented the walkie-talkie and the pager and pioneered the technology used in cellular and cordless phones, he never profited from these devices. People were not ready for a wireless world in the 1950's, and by the time they were, most of Gross's patents had expired. Today, cellular phones are a multimillion-dollar industry. The ability to securely send wireless data, which started with Gross's walkie-talkie, defines the modern world. Modern business, personal communications, and international transmissions could not exist without secure data links. Cell phones resist eavesdropping, computers exchange data through a wireless modem, and assistance is a push of a button away thanks to Gross's efforts.

—*Steven J. Ramold*

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See also: Edwin H. Armstrong; Martin Cooper; Lee De Forest; Reginald Aubrey Fessenden; Ivan A. Getting; Hiram Percy Maxim.

SIR WILLIAM ROBERT GROVE

British physicist

Grove's primary contributions to technological invention were two new kinds of electrical battery—the nitric-acid battery and the gas battery—but he also made a considerable contribution to theoretical science with his work on the "correlation of physical forces" and was a significant agitator for the professionalization of British science.

Born: July 11, 1811; Swansea, Glamorgan, Wales
Died: August 1, 1896; London, England
Primary field: Electronics and electrical engineering
Primary invention: Nitric-acid battery

EARLY LIFE

William Robert Grove was the son of John Grove, a magistrate and the deputy lieutenant of Glamorgan, and his wife, Anne (née Bevan). He was educated at home by a series of private tutors before attending Brasenose College, Oxford, in 1829, where he studied classics. He graduated in 1832 and went to London to prepare himself for a legal career, following in his august father's footsteps. He was admitted as a student at Lincoln's Inn on November 11, 1831, and was called to the bar on November 23, 1835.

Grove must have already developed a strong interest in natural philosophy at this time; he joined the Royal Institution in 1835 and was a founding member of the Swansea Literary and Philosophical Society in the same year. On May 27, 1837, he married Emma Maria Powles, the daughter of John Diston Powles of Summit House, Middlesex, a member of the Royal Institution whom he presumably met there. The couple had at least one son, Coleridge, and two daughters, Emily and Anna; the marriage lasted thirty-two years until Emma's death in 1879. Grove had been suffering health problems before the marriage, and the couple went on a long tour of the Continent thereafter; it was then that his interests in natural philosophy came into full flower.

Grove's first scientific publication was a letter to the *Philosophical Magazine* about the construction of electrical batteries, which were then inclined to decay very rapidly. He continued to publish letters on that subject and, while in Paris in 1839, he read a paper to the Académie des Sciences on a new kind of "voltaic pile." This was the first revelation of the nitric-acid battery that was to make his reputation as an inventor; Michael Faraday asked Grove to demonstrate the device at the Royal Institution following his return to England, which he did on March 13, 1840. By the end of the year, he had been elected a fellow of the Royal Society.

THE NITRIC-ACID BATTERY

The nitric-acid battery, or Grove cell, employed a zinc electrode suspended in dilute sulfuric acid and a platinum electrode suspended in concentrated nitric acid, separated by a porous ceramic pot. The battery produced a considerably higher voltage than previous models, doubling the voltage of its most powerful rival, the much more expensive Daniell cell. For this reason, the Grove cell became the battery of choice for telegraph systems in Great Britain and the United States from 1840 on and was not universally replaced until 1860, in spite of two serious defects. The first was that the voltage it generated diminished over time; the second was that the nitric acid tended to give off poisonous nitrogen dioxide gas, which could accumulate dangerously in a cramped but busy telegraph office.

The fact that Sir William Robert Grove made his battery freely available rather than patenting it, thus missing out on the payments that other pioneers of commercial telegraphy received—and which, as a lawyer, he would have been better placed than some of his rivals to claim and negotiate—may seem odd, given his subsequent crusade for the professionalization of science. What he wanted, however, was for scientific research to be better rewarded for its own sake, freed from the lottery that restricted success to the discoverers of patentable applications. The fact that the Grove cell became so important as a power source of early electrical technology presumably gave him a good deal of satisfaction, and there is no evidence that he regretted his failure to cash in on it. He would probably have been delighted to know that his gas battery, which had no useful applications at the time, would eventually become highly significant in the twentieth and twenty-first centuries as a nonpolluting fuel cell.

LIFE'S WORK

The professionalization of science was in its infancy when Grove became interested in experimental work. While he had to rely on his income as a barrister, Grove had difficulty finding time and money for further investigations. In 1841, however, he was appointed professor of experimental philosophy at the London Institution, founded in 1805 for the express purpose of bringing natural philosophers and businessmen together for the purposes of technological exploitation. His inaugural lecture on January 19, 1842, introduced the concept of the "correlation of physical forces," which suggested that physically active agencies—heat, light, electricity, magnetism, and so on—were mutually convertible and, in essence, merely different forms of the same phenomenon. Grove's theory was a precursor to the theory of conservation of energy that made his scientific reputation.

In 1842, Grove demonstrated another new kind of battery, which he called a gas battery. It worked by combining hydrogen and oxygen to produce steam and an output of electrical energy. It was of little practical value at the time, largely because it was more energy-expensive to produce the hydrogen and oxygen from steam than it was to redeem the energy thus "stored." Analysis of the way in which the water molecule could be dissociated into its component atoms and then recombined was, however, an important step forward in its own right, and Grove's device was directly ancestral to modern fuel cells, which use exactly the same principle and have the now significant advantage of producing no waste gases. The discovery won him the Royal Society's Royal Medal in 1847.

While he was at the London Institution, Grove worked with John Peter Gassiot on photographic chemistry. Grove also became increasingly impatient with the manner in which the Royal Society and other scientific societies were organized, along the amateurish pattern of gentlemen's clubs, and began to rail against rampant "nepotism" and "corruption." In 1843, he published an anonymous article in *Blackwood's Magazine* that was severely critical of the scientific establishment on these grounds. In 1844, he was appointed, somewhat controversially, as vice president of the Royal Institution. In 1846, still in a spirit of reformist zeal, he resigned his professorship at the London Institution because of the meager salary, but his scientific reputation increased as his book *On the*

Correlation of Physical Forces (1846) went through six editions, some of them augmented. He was elected to the council of the Royal Society and proposed to reform it by giving the council power over nominations to the society and limiting the annual number of nominations. The reforms were passed in 1847, prompting numerous resignations, giving Grove and his supporters effective control over the institution's future membership and direction. They formed the Philosophical Club as an inner circle within the broader organization. Although Grove failed in bids to be elected to higher positions within the Royal Society, he continued to use his council membership to further the professionalization of British science.

In the 1850's, Grove became very interested in the problem of electrical conduction in a vacuum, but his return to legal work left him devoid of laboratory facilities and increasingly short of time. In 1853, he became a Queen's Counsel on the South Wales and Chester circuit, appearing in some notable patent law cases regarding the early development of photographic technology. In 1855, he considered applying for the recently vacated chair of chemistry at Oxford University but did not think he could win a contested election. In 1866, he was elected president of the annual meeting of the British Association for the Advancement of Science (BAAS), held that year in Nottingham, and used his presidency to offer public support for the theory of evolution—the first BAAS president to do so. The last third of his address was a careful and cogent summary of all the evidence then available that the evolution of species had occurred in the past and was still occurring, aided by some kind of gradual and ongoing "spontaneous generation." (The idea of mutation was yet to be proposed.)

In 1871, Grove's legal career made further progress when he was appointed as a judge to the Court of Common Pleas; he was knighted the following year. In 1880, he was appointed to the Queen's Bench. He retired as a judge in 1887 and became a member of the Privy Council. He served on a Royal Commission on Patent Law and on the Metropolitan Commission of Sewers; the latter was an important body that supervised the construction of London's sewer system—one of the marvels of Victorian engineering. Grove died at his home on Harley Street in 1896 after a long illness and was buried in Highgate Cemetery. A lunar crater is named in his honor.

IMPACT

Grove's impact as an inventor and scientist was muted by his opposition to the way in which scientific endeavor in Great Britain was organized and remunerated, and he might have accomplished far more as an electrical experimenter had he not felt compelled to return to legal work in order to support himself and his family in what he considered to be reasonable comfort. He took out no patents, but his nitric-acid battery was widely adopted as a means of electricity generation. His gas battery, though of little practical value at the time, may yet prove even more significant as its direct descendant technology, the fuel cell, takes an increasingly important role in automotive technology in the twenty-first century. He was one of very few men of his own era to regard work as a Queen's Counsel and judge as mere drudgery, undertaken for money, while his heart was in pure and applied science. Historians of science will judge that his heart was in the right place.

—*Brian Stableford*

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See also: Michael Faraday.

OTTO VON GUERICKE

German physicist

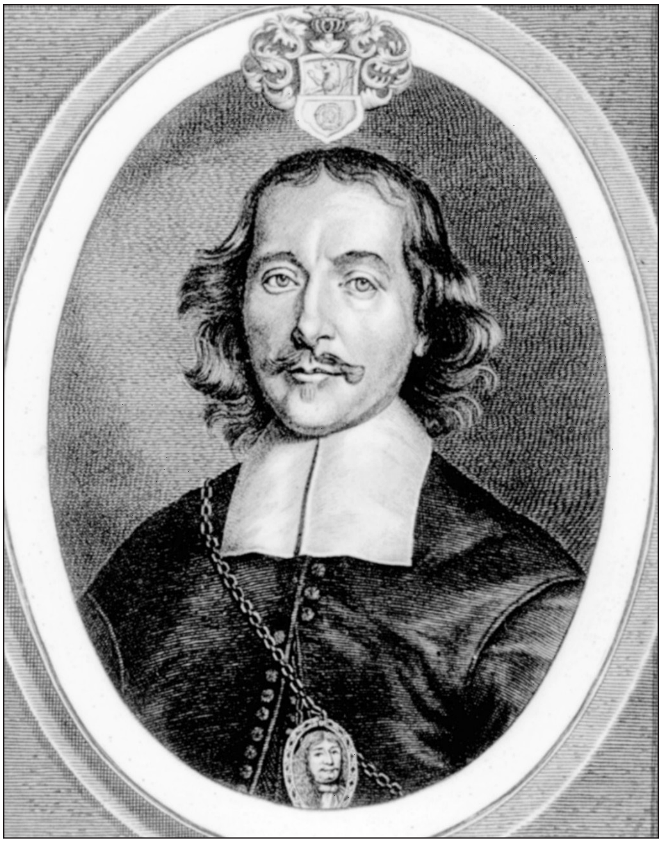
A theoretical physicist, Guericke challenged prevailing assumptions about the nature of atmospheric pressure and the properties of a vacuum and in the process invented a working model for the first vacuum pump.

Born: November 20, 1602; Magdeburg, Saxony (now in Germany)
Died: May 11, 1686; Hamburg (now in Germany)
Also known as: Otto Guericke
Primary fields: Mechanical engineering; physics
Primary invention: Vacuum pump

EARLY LIFE

Otto von Guericke (GAY-rih-kuh) was born to wealth in a family whose position in the town of Magdeburg dated back more than three centuries. As was the privilege of the aristocracy, Guericke attended a number of prestigious universities not so much to complete a degree as to investigate wherever his curiosity would lead. Thus, at fifteen, he entered the University of Leipzig to study the humanities (particularly law and philosophy). However, after his father's death when he was eighteen, Guericke returned home, where he continued his education (this time in jurisprudence), first at Helmstedt and then at Jena and eventually at Leiden in the Netherlands. In 1623 in Leiden, he began to study mathematics and engineering. He underwent the traditional grand tour, studying abroad in both France and England. He was drawn particularly to natural philosophy, or the study of the physical universe.

Guericke returned to Magdeburg in 1626 and married. Given his family's stature and his considerable education, Guericke was selected to serve as alderman, and his dedication to public service would continue for nearly five decades. In 1631, following the plundering of Protestant Magdeburg by the forces of the Holy Roman Empire during the Thirty Years' War, Guericke (who lost virtually his entire estate) was imprisoned briefly by the Swedish army before he was allowed to return to Magdeburg. There, drawing on his background in engineering, he directed the rebuilding efforts that included refortifying the city. In time, he began a lucrative business as a master brewer. In 1646, he was elected the revitalized city's burgomeister, the equivalent of mayor, a position he would maintain for more than thirty years. That career in public service extended to numerous important diplomatic assignments. In recognition of that service, Guericke was raised to peerage by Emperor Leopold I in January, 1666. Hence, "von" (connoting his new aristocratic status) was added to his name. As younger politicians sought to curtail his influence, Guericke in 1678 reluctantly gave up public office and two years later moved to Hamburg, where he lived with his son until his death on May 11, 1686.


Otto von Guericke. (Library of Congress)

LIFE'S WORK

It is remarkable that, despite his considerable public life and the demands of his business, Guericke maintained his deep interest in the sciences. His pursuit of a range of investigations across nearly three decades marks him as a prototypical Renaissance figure. His theoretical experiments touched on the fields of mathematics, engineering, electricity, meteorology, astronomy, and, most prominently, physics. Among his more notable experiments was the invention of a kind of rotating sulfur globe that, when friction was applied (Guericke would touch the globe with his hand), would send off sparks and attract and repel a variety of lightweight objects such as feathers, fabric, and paper. Guericke had no idea that the sparks were static electricity, but he and his audience relished the spectacle effects of the demonstration. In addition, Guericke completed important work in astronomical observations, most notably in the prediction of comets.

In the period of his most significant scientific work (1640-1655), Guericke was drawn to questions raised by the Copernican construction of the physical universe, particularly the nature of space itself and the assumption, grounded in the physical sciences since Aristotle, of the impossibility of a vacuum. The notion that "nature abhors a vacuum" (most vehemently argued by French philosopher René Descartes), called *horror vacui*, had led to a long tradition in philosophy that raised popular anxieties over the idea of empty space. Guericke, however, was not convinced: Experiments by Evangelista Torricelli in 1644 and by Blaise Pascal in 1647 indicated that air pressure was in fact a significant and potentially powerful force, that emptiness was hardly empty.

Determined to test the nature of air pressure and to verify the existence of a vacuum, Guericke began working in his backyard with the basic model of a modified water pump. He found that, in trying to evacuate the air from a barrel of water, the air seeped back into the barrel through the porous wood. That began an intense period of modifications and often frustrating results. By 1650 (the exact year is not known), Guericke had designed and built a prototype copper globe and discovered that he could pump out both water and air and create a powerful seal, or vacuum. It was the first working air pump. Besides his mechanical construction, Guericke was the first theoretical physicist to realize the implications of creating a vacuum. Over the next several years, he conducted tests that would verify (among other properties) that, in a vacuum, a flame could not be lit, the ringing of a bell could not be heard, and animal life could not be supported.

Guericke achieved considerable notoriety for a particularly dramatic demonstration of the sheer power of air pressure conducted at the court of Emperor Ferdinand III and the entire imperial diet in 1654 in Regensburg. Asked to demonstrate his air pump, he joined two identical hollow copper hemispheres into a sphere roughly fifteen inches in diameter and sealed it along fitted edges without any locks. Guericke proceeded to pump out the air, producing a vacuum within the sphere. Sixteen powerful horses divided into two teams pulling on either side of the tiny object failed to pull the sphere apart (although "eyewitness" testimony later put the number of horses at

THE VACUUM PUMP

When Aristotle stated that "nature abhors a vacuum" (*horror vacui*), that empty space tended to pull matter, gas, or liquid to it, he unintentionally justified centuries of increasingly rigid scientific postulations that conceived of a cosmos in which emptiness itself was something of a terror. Otto von Guericke's experiments in creating a vacuum in apparent refutation of that long-held argument rested on his review of two landmark experiments conducted just ten years earlier. In 1644, Evangelista Torricelli (a protégé of Galileo) performed an experiment to explain why well water was harder to draw when the water was below ground level. He used a glass tube of mercury to create an apparent vacuum. Three years later, Blaise Pascal's experiment measured different elevations and suggested that atmospheric pressure changed with altitude, indicating the enormous influence (and weight) of air pressure.

It was Guericke's historic contribution to actually create a vacuum—that is, to design a device (a vacuum pump) capable of removing molecules of gas from a sealed container. As a prototype, Guericke's pump was basic, what is now referred to as a positive displacement pump. One of the two copper hemispheres had a detachable tube that connected to the modified water pump, which had pistons that, when stroked steadily, removed the air from the enclosed sphere. The guiding principle was to use suction via the attached mechanism that, when pumped repeatedly, would actually expand the closed sphere to allow air to flow out of the chamber into a cylinder. As the pump was repeatedly exerted and closed off, given the differential in pressure, the vacuum seal became stronger. A one-way valve closed off the sphere when the air had been significantly removed (it was not an absolute vacuum). Once the evacuation had been completed and the pump detached, the sphere was held together by the tremendous force of air pressure.

At Regensburg, Guericke had two teams of horses harnessed to the tiny sphere (about fifteen inches in diameter), which they failed to pull apart. This dramatic experiment demonstrated the power of atmospheric pressure. His work disproved the long-standing hypothesis of *horror vacui* and laid the foundation for significant work in a variety of fields, including physics, pneumatics, and thermodynamics.

anywhere from thirty to forty-two). The demonstration made quite an impact: The court was amazed by straining horses thwarted by the tiny sphere held together by apparently nothing. Only when Guericke reentered air into the sphere did it come apart, and then it did so by itself without any pull. The demonstration—which Guericke later twice repeated, most notably in 1663 for the court of Friedrich Wilhelm I of Brandenburg (Berlin)—gave Guericke significant celebrity. Today, the hemispheres are known as "Magdeburg hemispheres."

Over the next decade, Guericke completed landmark experiments that defined the physical properties of the vacuum. He extended his interest in air pressure and vacuums to atmospheric experiments in meteorology. He invented the manometer, which measures atmospheric pressure, and significantly improved the design of the barometer as a tool for predicting weather. In the field of magnetism, he demonstrated that electrical attraction works in a vacuum—that a magnet, indeed electrical attraction itself, does not require air.

IMPACT

Historically, Guericke stands as a formidable Renaissance figure whose consummate interest in the implications of experimental physics was matched by a long and dedicated career of public service. Guericke's fifty-year record as a public servant represents a contribution that puts his work as amateur physicist in significant relief. His overseeing of the reconstruction of the infrastructure of the devastated Magdeburg—including the design and construction of tunnels, bridges, roads, and fortresses—and his participation in numerous delicate diplomatic negotiations and conventions following the Thirty Years' War are particularly notable. It is no surprise that the University of Magdeburg was renamed in his honor or that a heroic statue of him dominates the city's public square even today.

As a theoretical physicist, Guericke, whose work touched on so many different fields, represents the restless curiosity and intellectual energy of science's lost generation, which came between the death of Nicolaus Copernicus and the rise of Sir Isaac Newton—between the threshold era of initial hypotheses that heroically countered centuries of cosmological assumptions about the operations of the physical world and the era that saw the development of the instruments and observational data necessary to define that new cosmos into knowability. As such, Guericke, far more than an aristocratic dilettante dabbling in sciences, left behind a record of rigorous and painstaking experimentation, a spirit of inquiry free of religious or political biases. His most extensive research project into the nature of vacuums, for instance, redefined the conception of space itself and introduced the notion that the apparent emptiness between planets and stars was far more complicated and far more powerful a force than humanity had ever conceived. His research laid the foundation for significant work not only in pneumatics and physics but also in the fields of electricity, medical technology, thermodynamics, refrigeration, and ultimately space exploration.

—*Joseph Dewey*

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See also: Archimedes; Aristotle; Daniel Gabriel Fahrenheit; Michael Faraday; Galileo; Robert Hooke; Ewald Georg von Kleist; Pieter van Musschenbroek; Blaise Pascal; Santorio Santorio; Thomas Savery; Evangelista Torricelli; James Watt.

JOHANN GUTENBERG

German printer

By inventing the printing press, Gutenberg developed an innovative and extremely productive typographical process. In the mid-fifteenth century, his technological innovations—including the mechanical press and metal movable types—changed printing forever.

Born: 1394-1399; Mainz (now in Germany)
Died: Probably February 3, 1468; Mainz
Also known as: Johann Gensfleisch zur Laden zum Gutenberg (full name); Johann Gensfleisch zur Laden (birth name)
Primary field: Printing
Primary invention: Printing press

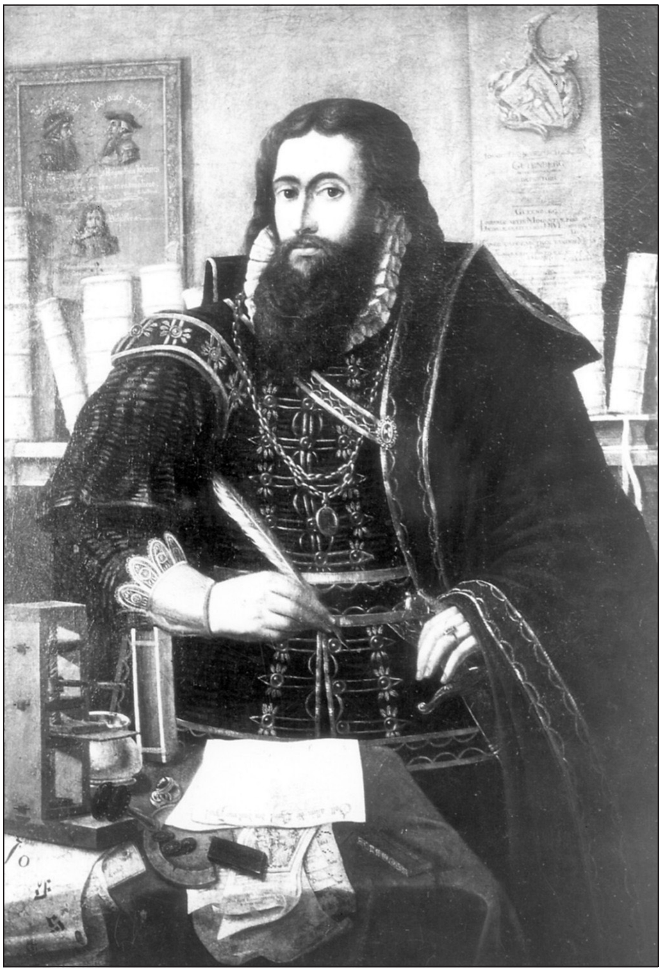
EARLY LIFE

Johann Gutenberg (YOH-hahn GOO-tehn-burg) was born Johann Gensfleisch zur Laden zum Gutenberg to a noble family in Mainz (now in Germany). He was the third son of a silversmith, Friele Gensfleisch, by his second wife, Else Wyrich, a storekeeper's daughter. He was trained in gold and silver work, which would have a great influence on his future invention. In 1411, his father had to exile himself to Strasbourg (now in France), following the revolts of the bourgeois guilds against the patricians in Mainz, and the rest of the family followed in 1428. At this time, perhaps to conceal his status as an exile, Johann changed his paternal surname to Gutenberg.

In Strasbourg, Gutenberg taught several arts and worked as a metallurgist. With Hans Riffe, Andreas Dritzehn, and Andreas Heilmann, he set up a company to create mirrors for pilgrims to Aachen, but the business failed. In 1438, Dritzehn died, and his heirs sued to be included in the partnership. The trial documents mention stone polishing, mirror making, and a "new art" that made use of a press, of certain pieces that could be separated and joined, lead forms (probably types), and "materials related to printing." It can be inferred that, as he worked as an engraver, Gutenberg was secretly testing his new art.

LIFE'S WORK

Nothing is known of Gutenberg's work between March 12, 1444, when he is last mentioned in the Strasbourg tax registers, and October 17, 1448, when his name reappears in a Mainz document for a small loan he received. What seems certain is that his search for a mechanized system of printing continued. He strove to surmount the technical limitations of printing of his time, which included xylography, a woodblock printing technique that came from China. Given the immense number of characters in the Chinese language, this technique would not be developed in China but in Europe from the fourteenth century on. The twenty-five letters of the Latin alphabet, separately carved in wood, were arranged to form words; thus began the typographic press. The number of prints that could be made was, however, scant, and the finish was irregular. The Dutchman Laurens Coster is said to have printed with movable type as early as 1430,



Johann Gutenberg. (Library of Congress)

The Printing Press

Johann Gutenberg is the inventor of typography—the art of laying out and multiplying texts and images on paper. Taking advantage of the progress made in metallurgy in his time, he set up around 1450 the first printing house in history. It was equipped with a mechanical press, movable type, high-quality paper, and oil-based inks. It had two sections: one for composition, one for printing. Gutenberg devised an innovative typographical five-stage process: punch cutting, matrix fitting, type casting, composing, and printing. The first stage consisted of carving back to front the shape of each letter or symbol on a steel punch. This was then hammered on a small copper piece called a matrix. When the matrix was fixed on a mold's base into which liquid metal was poured, a piece of type was created—a back-to-front, three-dimensional representation of a letter or symbol cast in an alloy of lead, tin, and antimony.

The presses used by Gutenberg and his successors were wooden. The upper part of the press was normally fixed to the ceiling; once the composed type had been locked and inked on the bed of the press, the (usually moist) paper was screwed down against it by means of a movable flat surface, or platen. The press had rails for the printing block to be extracted and to recover its original position. It was a slow and laborious operation: About 250 prints were made each hour, and only one side was printed at a time. Nevertheless, the highly technical process devised by Gutenberg made it (for five centuries) the only printing technique for large print runs. In the course of time, other technical processes—lithography, flexography, engraving, the rotary press, Linotype, offset printing, and modern digital printing—would enhance the performance of this art.

The extraordinary social, artistic, and intellectual impact of the printing press cannot be overstated. Books became valued as objects in themselves; great care was taken with illustrations, typefaces, book covers, and so on. Knowledge became more dynamic, spreading as it had never done before. Periodical publications, propaganda leaflets, pocket editions, and bibliographical collections were born. Public and private libraries increased immensely. People read more and were heard on public affairs. Readers had access to written sources, allowing for personal interpretation of literary texts. A common epistemological framework for all kinds of research became available. The invention of the printing press changed the mentality of human society and marked the beginning of a new age.

but this claim lacks support. Most scholars now credit Gutenberg with inventing the printing press.

Gutenberg, after a number of tests, succeeded in mechanizing the printing process. His workshop brought together the basic components of modern typography: special paper, an oil-based printing ink, a mold with punch-stamped matrices from which movable metal types could be cast, and a new press that he adapted from wine presses. A new typographical process based on composition and printing was thus inaugurated. Typography took immediate advantage of Gutenberg's invention: Manuscript proof corrections were easily done, the number and quality of prints exceeded that of the Middle Ages, uniformity and perdurability in printing were achieved, the graphic possibilities became almost limitless, and prints became cheaper.

However, Gutenberg did not have enough money to set up his printing house. Foreseeing the economic advantages of the invention, the German moneylender Johann Fust became associated with Gutenberg around 1450. Fust first loaned him 800 guilders for the equipment, at an interest rate of 5 percent. Two years later, he promised him 300 guilders more as a share in the invention Gutenberg called "Das Werk der Bücher" (the work of books). Gutenberg set up his first known printing plant in Mainz. Peter Schöffer, Fust's son-in-law and Gutenberg's disciple, joined them in 1452, the year the team's great work began to take shape: the Gutenberg Bible, also called the Mazarin Bible (so called because the first copy described by bibliographers was located in Cardinal Mazarin's library) or the Forty-two-Line Bible (so called because each page has forty-two lines). The work, completed in 1455, is known for its excellent typographic quality and great beauty.

Gutenberg's partnership with Fust and Schöffer did not last. Fust did not wait for the over 150 copies that were being printed to be sold, and he judicially claimed from the inventor some 2,000 guilders. Gutenberg lost in court and was sentenced to give back the still uninvested capital and pay the interest due. In 1455, the partnership was dissolved. Fust and Schöffer kept the printing plant and put the Bible copies on the market in early 1456. In 1457, they published the *Mainzer Psalterium*, the first work to include the printing date and the name of the printers. Gutenberg must have also taken part in this publication before he quit the partnership.

These were times of economic hardship for Gutenberg. Around 1457, he joined one of the many printing houses already established in Mainz, whose manager was the syndic Conrad Homery. Many books were then published in the city; among them were Johannes Balbus's *Catholicon* (1460), the Thirty-six-Line Bible (before 1461), school textbooks, dictionaries, and astronomical calendars in the vernacular. Gutenberg neither dated nor signed any of his books, so it is impossible to determine which ones are his work.

In 1462, Mainz was sacked by the troops of Adolph II of Nassau, archbishop of the city. Like many other printers, Gutenberg suffered heavy financial losses, but he remained in the city. It is said that the archbishop took him into his palace in 1465, made him a knight of the court, and granted him a salary and privileges in gratitude "for the services performed so far and for those he will perform in the future." Gutenberg's financial situation improved considerably, and he continued to print books. He spent the last years of his life between Eltville and Mainz, where he died on February 3, 1468. In 1900, a museum was erected in his native city, where his press and workshop have been re-created.

IMPACT

That Gutenberg was the real inventor of the printing press is unquestioned today. It was he who devised, equipped, and started the first printing house in history. Between 1450 and 1465, the printing press started to be used for industrial purposes. The disciples of the first typographers taught the new printing technique throughout Europe. Fifty years after Gutenberg's death, presses had been set up in 270 European cities; forty thousand books had been printed by then, amounting to over ten million volumes. In 1476, a Greek grammar was printed in Milan, and in 1488 a Hebrew Bible in Soncino. In Spain, at the request of Cardinal Cisneros, the Complutensian Polyglot Bible was made (1514-1517). The printing press reached America in 1539, when Juan Cromberger brought it to Mexico.

The sixteenth century saw the rise of the great dynasties of printers (the Manutii in Italy, the Estiennes in France, the Plantins and Elzevirs in the Low Countries, for example), precursors of the manufacturing press. State, church, and cultural representatives were soon aware of the advantages conveyed by Gutenberg's typographic art. The Renaissance humanists multiplied the editions of the works of classical antiquity (pocket editions began in 1500 with Aldus Manutius's *Virgilius*) and encouraged the creation of large libraries. The Protestant Reformation made ample use of the printing press, particularly to spread the reading of the Christian source texts in the vernacular. (The German translation of Martin Luther's Bible was printed in 1534.) The printing press was also used for the circulation of propaganda during the political and religious strifes of the sixteenth and seventeenth centuries. The scientists of the modern era used the printing press to relate their ideas and discoveries to a world imbued with the mechanical culture. It took less than a century for the trading bourgeois to set up networks for the diffusion and selling of books, thus favoring the establishment of mercantile associations.

—*Avelina Carrera*

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See also: William Bullock; Cai Lun; Chester F. Carlson; Ottmar Mergenthaler; Mark Twain.

FRITZ HABER

German chemist

Haber's research in chemistry paved the way for commercial production of synthetic nitrogen fertilizers, thus enhancing global agricultural productivity. His work was also critical in supplying his native Germany with conventional munitions and chemical weaponry during World War I.

Born: December 9, 1868; Breslau, Silesia, Prussia (now Wrocław, Poland)
Died: January 29, 1934; Basel, Switzerland
Primary fields: Chemistry; military technology and weaponry
Primary inventions: Synthetic fertilizers; Haber process

EARLY LIFE

Fritz Haber (HAY-bur) was born on December 9, 1868, in Breslau, Silesia, Prussia (now Wrocław, Poland). The son of Siegfried Haber, a wealthy merchant dealing in dyes and pharmaceuticals, Fritz was a member of an esteemed and well-connected family in his town. His mother, Paula, died in childbirth.

Fritz Haber. (©The Nobel Foundation)

Haber's early schooling took place at the *Volksschule*, or formal school. He then enrolled at the St. Elizabeth classical school in Breslau, where he studied for nine years. Instead of serving as an apprentice, training that would have prepared him for taking over the family business, Haber convinced his father to allow him to attend university. In 1886, at the age of eighteen, Haber entered Berlin's Friedrich-Wilhelms-Universität (now Humboldt University) to study chemistry and physics. From then until 1891, Haber also studied chemistry at the University of Heidelberg and the Technical School at Charlottenburg. Following his university studies, Haber worked in his father's chemical firm. He eventually decided to pursue a career in scientific research.

In 1892, at the age of twenty-four, Haber converted from Judaism to Christianity, presumably to facilitate his academic and professional career. He became fiercely nationalistic; some historians claim he adopted German nationalism as his "religion." In 1894, Haber accepted an assistantship in the Department of Chemical and Fuel Technology at the Technische Hochschule in Karlsruhe, where he worked until 1911. He began as assistant to the professor of chemical technology, Hans Bunte; habilitated as Privatdozent in 1896; and was designated Extraordinarius in 1898. In 1906, Haber was appointed professor of physical chemistry and electrochemistry and director of the institute established at Karlsruhe.

Faculty colleagues Bunte and Carl Engler introduced Haber to the study of petroleum. Haber's subsequent work was strongly influenced by these men. His thesis addressed his experimental studies of the decomposition and combustion of hydrocarbons. In 1911, Haber succeeded Engler as director of the Institute for Physical and Electrochemistry at Berlin-Dahlem.

LIFE'S WORK

A group of prominent chemists collaborated to create an elite German institution dedicated to basic and applied research in chemistry. By 1911, the Kaiser Wilhelm Institute for Physical Chemistry and Electrochemistry was inaugurated in Berlin, and Fritz Haber was invited to serve as its first director. The inception of the institute coincided approximately with the start of World War I (August, 1914); as a result, the mission of the institute was abruptly and significantly altered. Haber, being passionately patriotic to Germany, offered his services to the War Ministry. Research into fundamental chemical processes was set aside in favor of research projects of immediate relevance to the war effort. The institute was placed under control of the military.

One of Haber's primary research goals during the war period was to increase the supply of raw materials for the war effort. Of great significance was Haber's work in procuring nitrogen, to be used both for fertilizer manufacturing and for high explosives and other weaponry. Haber overcame the obstacle of supplying nitrogen for both agricultural and wartime needs by inventing a system for synthesis of ammonia from hydrogen and nitrogen using an iron catalyst. The process was subsequently scaled up by Badische Anilin- und Soda-Fabrik (BASF) chemist Carl Bosch, thus giving the title "Haber-Bosch process" (or "Haber process"). Nitric acid was produced from the ammonia and then used as the precursor in a wide array of materials, including inorganic fertilizers. Nitric acid is also a raw material for the production of chemical high explosives and other munitions.

SYNTHETIC FERTILIZERS

Three elements are required in large quantities for growth of agronomic, vegetable, horticultural, and other crops: potassium (K), phosphorus (P), and nitrogen (N). Extensive deposits of phosphate rock and potash occur worldwide and provide adequate sources of phosphorus and potassium, respectively. A century ago, the largest nitrogen source for fertilizer manufacture occurred in enormous bird guano deposits (saltpeter, $NaNO_3$) located along the coast of Chile. These deposits had accounted for more than 60 percent of the world's supply for most of the nineteenth century. This fertilizer material was, however, rapidly disappearing and had its share of practical drawbacks to its use.

During the period from 1830 to 1930, world population doubled from one to two billion. As population increased, so did demand for agricultural production and concurrent fertilizer use. Worldwide demand for nitrogen-based fertilizers began to exceed the known supply. Furthermore, only a few plants were known to have the capability to directly convert atmospheric nitrogen to so-called fixed nitrogen compounds—that is, those which are directly usable by other biota. In the early twentieth century, three methods were developed to fix nitrogen, either for direct use or to further react to produce fertilizers. The cyanamid process and the electric-arc process were considered to be of little value in making fertilizer. Fritz Haber invented a system for large-scale synthesis of ammonia from hydrogen and nitrogen, both abundant and inexpensive gases, using an iron catalyst. High temperatures (about 500° Celsius), and high pressure (about 3,000 psi) were used to combine the gaseous nitrogen (N_2) and hydrogen (H_2) into ammonia. Haber was assisted by Robert Le Rossignol in designing the laboratory apparatus. Once atmospheric N_2 is "fixed" to ammonia, the ammonia is subsequently oxidized, using the Ostwald process, to make nitrates and nitrites. These compounds are essential for the production of both nitrogenous fertilizer (that is, ammonium nitrate) and high explosives (trinitrotoluene, TNT).

In the 1920's, the first ammonia manufacturing plants based on the Haber-Bosch process went into production in the United States and Europe. The Haber-Bosch process changed the way nitrogen fertilizers are produced and has increased their availability. The process was a critical catalyst for the Green Revolution of the late twentieth century.

Haber went on to develop and encourage the use of chemical weapons and was intimately involved in their deployment, believing that such weapons would bring World War I to a quick conclusion in favor of Germany. Haber, backed by the chemical industry, persuaded Germany's military leadership to stage a battlefield test of a chemical weapon. Haber supervised the initial deployment of chlorine on the western front at Ypres, Belgium, on April 22, 1915. A six-kilometer stretch of the front was exposed to 167 tons of chlorine released from 5,700 gas cylinders. Figures vary; however, between 5,000 and 15,000 Allied troops were killed or wounded that day. The lethality of the chlorine attack at Ypres convinced the German military to adopt chemical warfare. Haber was promoted by an imperial decree to the rank of captain. Haber's efforts in chemical weapons research resulted in the suicide of his first wife, Clara Immerwahr, who was herself a very able chemist. She firmly believed that science should be applied for constructive purposes, not for making weapons of mass destruction.

As World War I continued, Haber's institute developed into a major research laboratory for both development of chemical weapons and methods of protecting against such weapons. For example, colleagues at the Kaiser Wilhelm Institute developed a respiratory filter for a gas mask. After World War I, Haber's institute became the world's leading center of research in physical chemistry, staffed with a distinguished coterie of international scientists. Haber again devoted himself to fundamental research. He conducted studies on insecticide formulations that could be used to control flour moths and other agricultural pests. The hydrogen cyanide-based gas developed by his institute was found to be quite effective. During the late 1920's and early 1930's, this so-called Zyklon B helped to protect the German food supply. This gas, however, would eventually be used in the extermination of millions of innocents condemned to the Nazi death camps of World War II.

Haber's military activities eventually led the Allies to label him as a war criminal. Haber was never convicted for these crimes; however, his direct involvement with development of compounds designed solely for killing posed legitimate problems for his nomination for the Nobel Prize in Chemistry. Use of chemical weapons had been forbidden since the 1899 Hague Convention with Respect to the Laws and Customs of War on Land.

Haber's institute rapidly deteriorated in 1933, when, with the rise of the Nazism and its anti-Semitic policies, he became vilified as the "Jew Haber." Nearly all his staff had to resign, as did Haber, in 1933. He was offered a position at Cambridge, and he left Germany in that year.

For some time, Haber had been suffering from heart disease. Concerned about English winters, he moved to Switzerland. He planned to visit the Daniel Sieff Research Institute in Palestine, but while traveling he suffered a heart attack in Basel and died there in January, 1934, at age sixty-five.

Haber is reported to have died a broken and defeated man. He was cremated, and his ashes, together with those of his wife Clara, were buried in Basel's Hornli Cemetery.

IMPACT

Haber examined a wide range of projects in physical chemistry and is credited with numerous significant discoveries. His work on the fixation of nitrogen from the air, however, resulted in his award of the Nobel Prize in Chemistry in 1918. It is believed that Germany would have run out of nitrates by early 1916 if it had not been for the discoveries and applications of Haber and his colleagues. Germany's use of the Haber process to make ammonia, and the Ostwald process to convert ammonia into nitric acid and nitrates, were both instrumental in prolonging the war. Germany was no longer dependent on foreign supplies of chemicals to support its agriculture or its progress on the battlefield. Fertilizers and explosives could now be made from readily available natural resources such as air and fossil fuels. Haber's work led to the development of a substantial high-pressure industry and many applications of metallic and other catalysts.

In addition to the Nobel Prize, Haber received many other honors during his lifetime. The Institute for Physical and Electrochemistry at Berlin-Dahlem was renamed the Fritz Haber Institute after his death. On the darker side, Haber is often referred to as the "father of modern chemical warfare." He is said to have viewed gas warfare "as an intellectual challenge," telling industrialist Carl Duisberg that "gas weapons and gas defense turn warfare into chess." His exhaustive efforts in supporting the German war effort altered the relationship among the sciences, the military, and the chemical industry.

—*John Pichtel*

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See also: Friedrich Bergius; Carl Bosch; Alfred Nobel; Ernst Ruska.

CHARLES MARTIN HALL

American chemist

Hall discovered an inexpensive method for producing pure, metallic aluminum from its ore using electrolysis. He successfully developed his process into large-scale industrial production and became one of the founders of the Aluminum Company of America (Alcoa).

Born: December 6, 1863; Thompson, Ohio
Died: December 27, 1914; Daytona Beach, Florida
Primary fields: Business management; chemistry
Primary invention: Hall-Héroult electrolytic process for aluminum refining

EARLY LIFE

Charles Martin Hall was born in 1863 at the church parsonage in Thompson, Ohio, near Cleveland. In 1873, the family moved to Oberlin so that Hall's older brother and sister could live at home while attending college. Oberlin College was the first institution of higher education in America to admit women as students. Hall was a good student who loved to read. He finished high school in three years and then attended Oberlin Academy for a year of college preparatory courses. He was excited to read about Thomas Alva Edison's invention of the incandescent light bulb. He expressed admiration for George Westinghouse, inventor of the air brake system for trains that had made him a millionaire at age thirty. Hall got permission from his parents to work on chemical experiments in a woodshed behind their house. He obtained glassware, a gasoline stove, various chemicals, and materials to make his own electric batteries. He was a college junior in 1882 when he took his first course in chemistry under Frank Jewett.

Jewett had graduated from Yale University with a Ph.D. in chemistry, followed by a postdoctoral fellowship in Germany before coming to Oberlin. Jewett had obtained some samples of metallic aluminum in Germany that he liked to show to his classes. The ore containing aluminum is very abundant on Earth, but refining it to obtain the pure metal had proved to be extremely difficult. Jewett gave a memorable lecture in which he stated that the person who found an inexpensive process for refining aluminum would make a great contribution to humanity and also would become very wealthy. Hall told a classmate that he wanted to be that person.

LIFE'S WORK

From an article in *Scientific American*, Hall had learned that magnesium metal could be refined from its ore by means of electrolysis, so he decided to see if that process would work for aluminum as well. A demonstration of electrolysis frequently done in introductory chemistry classes uses copper sulfate dissolved in water. Two electrodes are partially submerged in the solution and are connected to the positive and negative terminals of a battery. Students can observe how the negative terminal gradually becomes coated with metallic copper because the positive copper ions in the solution are electrically attracted to it.

The most common ore containing aluminum is called bauxite. Its main component is aluminum oxide, which is a combination of aluminum and oxygen atoms. Aluminum oxide, however, is insoluble in water. For electrolysis, it is essential that the material can be dissolved so that the ions can migrate through the fluid to the electrodes. Hall experimented for several months trying to find a chemical solvent for aluminum oxide, but without success. His next idea was to use a very hot mineral bath into which he would stir some finely powdered aluminum oxide, hoping that it would dissolve. He built an insulated oven around his small gasoline burner. A crucible placed into the oven served as the container for various minerals to be tested. Some minerals would not melt in his crude oven, and others that did melt would not dissolve the aluminum oxide. His results were all negative until he tried a mineral called cryolite. To his happy amazement, aluminum oxide dissolved in molten cryolite like sugar in water.

Having found a solvent for aluminum oxide, Hall was ready to try electrolysis. He mounted two electrodes in the crucible inside the oven, with wires coming out to a battery. When the oven was hot and the battery was connected, he observed gas bubbling up at the positive terminal. This was caused by oxygen ions from aluminum oxide combining with carbon from the electrode to form carbon dioxide gas. Hall hoped that aluminum ions would be collected at the other electrode. After running the experiment for several hours, he poured the molten cryolite into an old iron frying pan to let it cool. Then he used a hammer to shatter the cryolite into pieces, among which he found some small pellets of shiny aluminum metal. The date was February 23, 1886, which was important in order to establish priority for his later patent application. His older sister, Julia, and Professor Jewett were his witnesses.

In July of 1886, Hall went to Washington, D.C. to file a patent application, which he entitled "The Process of

Reducing Aluminum by Electrolysis." To his surprise, the Patent Office informed him that an application already was pending for the same basic process, filed by Paul Héroult of France in April of that year. According to U.S. law, a patent is issued on the basis of the date of discovery, and since Hall had specific documentation and witnesses for his date of discovery, he was awarded the patent.

Hall next needed to find investors who would finance a start-up company to manufacture and sell aluminum. He demonstrated his apparatus to potential financial backers in Boston, but without success. His breakthrough came when he met Alfred Hunt, a well-established metallurgist in the steel industry in Pittsburgh, Pennsylvania. Hunt and several partners made a commitment for $20,000 and founded the Pittsburgh Reduction Company to set up a pilot plant. To supply electricity for electrolysis, they purchased a Westinghouse electric generator powered by steam, having an output of 2,000 amperes. The pilot plant operated successfully for three years, producing over eighty thousand pounds of aluminum.

Based on the success of the pilot plant, the stockholders voted for a major expansion. They issued new stock for $1 million, with the financier Andrew W. Mellon as a participant. A new facility was built near Niagara Falls, New York, because hydroelectric power had just come online at relatively low cost. In 1907, the Aluminum Company of America (Alcoa) was founded, with Hall as its vice president. Hall died of leukemia in 1914 at the age of fifty-one. Donations to Oberlin College from his will and from earlier gifts totaled over $20 million. The Oberlin Chemistry Department has a display case containing two of the original aluminum pellets from February 23, 1886, popularly called the "crown jewels" of the college.

INDUSTRIAL PRODUCTION OF ALUMINUM FROM BAUXITE ORE

High-grade deposits of bauxite, containing up to 60 percent aluminum oxide, are found most abundantly in Australia, Brazil, and China. Aluminum oxide first has to be extracted from its ore, and then the Hall-Héroult electrolytic process is used to refine the pure metal. Bauxite ore, usually obtained by open-pit (surface) mining, is crushed and washed, and then mixed with caustic soda (sodium hydroxide) at high temperature. The aluminum oxide dissolves while the other components remain as solids and are removed by filtration. Seed crystals are added to precipitate the aluminum oxide. After heating in a kiln to evaporate the water, a white powder of aluminum oxide is left behind.

Electrolytic separation of aluminum metal from its oxide is done in large, steel pots lined with carbon. As in Charles Martin Hall's patented process, molten cryolite acts as the solvent. A carbon rod, inserted into the cryolite from above, is lowered until it comes close to the bottom of the pot. The rod is the positive electrode and the carbon lining of the pot is the negative electrode. Oxygen ions are electrically attracted to the rod, forming carbon dioxide gas, and aluminum ions are attracted to the negative lining, forming molten aluminum metal that sinks to the bottom of the pot. The cryolite is kept hot by resistive heating from the large current flowing between the electrodes, so no external oven is needed. The molten aluminum is siphoned off into a large crucible, from where it is poured into molds to produce solid ingots of metal.

When refined aluminum is removed from a pot, fresh aluminum oxide must be added in order to maintain operation without interruption. Carbon rods gradually wear away due to oxidation and must be replaced periodically. A typical pot operating with 2,000 amperes of direct current will produce about sixteen kilograms (seven pounds) of aluminum per day. At a large refinery, there may be a hundred or more pots operating in a long line. Refineries usually are situated near hydroelectric power plants because electricity constitutes the largest cost in aluminum production.

IMPACT

Aluminum was unknown to the general public until 1884, when it received widespread national publicity because of its use for the Washington Monument in Washington, D.C. With a height of 550 feet, this was the tallest construction project in the world at the time, and a lightning rod needed to be mounted at the top. The chief engineer decided to use aluminum because it has good electrical conductivity and does not tarnish. At the time, aluminum was considered a semiprecious metal with a cost per ounce equal to that of silver. The Frishmuth Company of Philadelphia was given a contract to make an aluminum pyramid, nine inches high, that would form the cap of the monument. The highly polished pyramid was put on display at Tiffany's jewelry store in New York for people to admire. It was installed in December of 1884, with a copper rod connecting it to the iron scaffold of the elevator shaft leading down to ground.

Hall discovered the electrolytic method for refining aluminum in 1886. Within three years, the small pilot plant in Pittsburgh was producing several thousand pounds per month costing under one dollar per pound. Since that time, aluminum has become the material of choice for a huge number of applications. Aluminum doors, window frames, siding, and gutters are popular in house construction. Aluminum alloys are widely used to manufacture strong beams for large architectural applications. In the aircraft industry, aluminum used for the engine, frame, exterior skin, landing gear, and interior paneling typically makes up 80 percent of a plane's weight. For food packaging, aluminum foil, trays, and billions of beverage cans provide a huge market. In sports equipment, aluminum is used for tennis racquets, skis, baseball bats, canoes, and fishing boats. In automobiles and trucks, aluminum is used for radiators, engine blocks, automatic transmissions, wheels, air conditioners, and body panels, since lighter weight improves the gas mileage. Aluminum wires do not corrode, so they are commonly used for underground electrical cables and for high-voltage cross-country transmission lines. Cooking utensils, appliances for the home, tools, and other consumer goods often are made from aluminum. Except for iron and steel, aluminum has become the most widely used metal in the modern world.

—Hans G. Graetzer

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See also: J. Georg Bednorz; Herbert Henry Dow.

H. TRACY HALL

American physical chemist

Hall invented the experimental method for producing synthetic diamond, which is used for numerous industrial applications, electronics, and the jewelry business. Known as the "father of man-made diamond," Hall was granted nineteen patents that included inventions dealing with high-pressure, high-temperature equipment, as well as various methods for making diamond and other hard chemical compounds.

Born: October 20, 1919; Ogden, Utah
Died: July 25, 2008; Provo, Utah
Also known as: Howard Tracy Hall (full name)
Primary field: Chemistry
Primary invention: Synthetic diamond

EARLY LIFE

Howard Tracy Hall, the son of Howard and Florence Tracy Hall, was reared with his four brothers on a farm in Marriott, Utah, a rural town north of Ogden. As a young boy, Hall learned the value of hard work on the family farm and enjoyed roaming the surrounding fields in Marriott. When his family traveled to Ogden to obtain supplies, Hall and his brothers would spend time at the Ogden City Library, where Hall became highly interested in reading about great scientists, particularly Thomas Alva Edison. At the age of nine, Hall decided that sometime in his future he would work as a scientist for Edison's company, General Electric (GE).

In 1939, Hall earned his associate degree in science from Weber College in Ogden. He then attended the University of Utah. There he met Ida-Rose Langford, marrying her in 1941. After completing his B.S. degree in chemistry in 1942, he earned his master's degree from the University of Utah the following year under the direction of G. Victor Beard. Beard was the first scientist to encourage Hall to follow his passion—conducting experiments dealing with diamond synthesis.

From 1944 to 1946, Hall served as a Navy ensign in World War II. After returning to the University of Utah in 1946, Hall, under the tutelage of famed chemist Henry B. Eyring, began thinking more about the theory associated with the conversion of carbon to diamond. He earned his Ph.D. in physical chemistry from the University of Utah in 1948. Two months later, Hall accepted a position as a chemist at the General Electric Research Laboratory in Schenectady, New York, a fulfillment of his childhood dream.

In 1951, GE announced that it would tackle the problem of producing synthetic diamond because of its great value in industrial applications. Volunteers were sought to help with the project, known as Project Superpressure. Hall volunteered and, along with fellow chemist Robert H. Wentorf and a group of physicists led by Herbert M. Strong and Francis P. Bundy, pursued the problem. After thoroughly analyzing a variety of questions related to the chemistry of diamond, Hall decided that the first barrier to overcome was the invention of high-temperature, high-pressure equipment that could convert either graphite or the carbon in carbonates into diamond.

LIFE'S WORK

Initial experiments conducted during Project Superpressure used a Carver press, a modified twenty-ton automobile jack. After the research group designed a new, versatile press that would take about two years to build, Hall pursued experimentation using a small bench press and a modified water-operated Watson-Stillman press that leaked water profusely. Although resisted by other scientists in the group who felt that he was intruding into their areas of expertise, Hall continued to develop unique variations of piston-cylinder devices that were formulated by the group but that were not working because of mechanical failure at the junction of the walls and the bottom of the cylinder bore. Hall finally solved the problem by eliminating the cylinder bottom altogether by placing two conical-shaped semi-pistons back-to-back. Internal pressure was confined radially by a belt of prestressed steel bands. Hall was eventually granted a U.S. patent for the high-pressure, high-temperature belt apparatus in 1960. It could generate 120,000 atmospheres of pressure and sustain a temperature of 1,800° Celsius in a working volume of about one-tenth of a cubic centimeter for intervals of several minutes at a time.

Although it was thought that the extreme pressure and temperature conditions available in the belt apparatus were more than sufficient to directly transform graphite into diamond, experiments proved otherwise. Since direct transformation to diamond did not occur, Hall tried hundreds of indirect approaches using various catalysts to speed up the transformation. After numerous failures, GE was considering abandoning the project to produce synthetic diamond.

With only a few days remaining before GE was to scrap Project Superpressure, on December 16, 1954, Hall used his belt apparatus made with a tungsten carbide chamber to run an experiment that used graphite, along with troilite (iron sulfide) to act as a catalyst; a disk made of tantalum was used to conduct electricity into the cell containing the sample. The pressure in the belt apparatus was near 70,000 atmospheres (about one million pounds per square inch) and the temperature was near 1,600° Celsius. Upon breaking open the cell after several hours of run time, Hall observed numerous shiny, octahedral crystals cleaving to the tantalum disk. After regaining his composure, Hall examined the crystals under a microscope and found that they contained structures that looked like natural diamonds. Further analysis showed that the crystals scratched sapphire, burned in oxygen to produce carbon dioxide, and had the density and refractive index of natural diamond. An X-ray diffraction pattern produced a few days later confirmed that the crystals were diamond. During December 17-30, Hall experimented with varying the pressure and temperature to determine the best pressure-temperature range in which diamond would form. On December 31, GE physicist Hugh Woodbury duplicated Hall's results and also produced synthetic diamonds.

Once the achievement of the synthesis of diamond was formally announced by the media on February 15, 1955, Hall was highly sought after, with job offers from numerous high-techology companies. Because of the lack of credit received by Hall from GE for his invention of the apparatus and the method for synthesizing diamond, he accepted a position as a professor of chemistry and director of chemical research at Brigham Young University (BYU) in 1955. At BYU, Hall invented a completely new high-pressure machine for making diamond, known as the tetrahedral press. It contained four anvils (press members) that converged on a tetrahedral volume. He was granted a U.S. patent for the tetrahedral press on December 29, 1959. Hall built and sold tetrahedral presses and invented an improved apparatus, the cubic press, in 1964. The cubic press had six anvils that provided pressure simultaneously onto all the faces of a cube-shaped volume. In 1966, Hall and two other BYU professors, Bill Pope and Duane Horton, formed Megadiamond, a company that manufactured high-pressure equipment and produced synthetic diamond.

In his personal life, Hall was a devoted husband and father. He often said that his greatest accomplishments were his home and family. He was a devoted member of the Church of Jesus Christ of Latter-day Saints, serving as a bishop and in many other positions of responsibility and leadership. During his spare time, he enjoyed farming and growing fruit trees.

IMPACT

Hall is the epitome of an individual who never gives up no matter what the odds may be. While working at GE, after hundreds of failed experiments, an increasingly impatient management, and intense rivalries and competition among fellow researchers, Hall endured and pursued his dream of making diamond until he succeeded. His inventive genius and perseverance led to his receiving nineteen patents, which included eleven patents for high-pressure, high-temperature apparatuses and five patents for making diamond and diamond composites. Until the late 1990's, every diamond-making press in the world was based on designs invented by Hall.

The first synthetic diamonds produced by Hall and others were very small, but just right for a variety of industrial applications that involved cutting, grinding, and polishing other materials. By 1954, industry was using about 14 million carats of diamond in manufacturing processes, all coming from natural sources. By 1996, industrial diamond usage had risen to more than 505 million carats, with more than 90 percent being produced synthetically using Hall's inventions. Human-made diamonds are used for applications in the aerospace, mining, manufacturing, petroleum, and automotive industries. They can be found in drill bits, masonry saws, cutting tools, and polishing machinery.

As Hall improved his tetrahedral and cubic presses, electronic applications soon emerged, followed by the production of diamonds large enough to be used in the jewelry business, starting in 1970. Industrial diamond in-

SYNTHETIC DIAMOND

High-pressure, high-temperature presses are needed to squeeze and press carbon into the molecular arrangement of diamonds, as well as into the formation of other hard, crystalline materials, such as cubic boron nitride. H. Tracy Hall's tetrahedral press contained four movable press members, or anvils, while his cubic press contained six press members. Forward and reverse thrusting forces were provided by hydraulic rams. In Hall's presses, a hydraulic ram was connected directly to each movable press member. Hall's belt and cubic press devices have been successfully used in numerous commercial applications, while his tetrahedral press has mainly been employed in experimental, laboratory applications. Hall vastly improved his cubic press by incorporating a guide apparatus to move the press members in a simultaneous, synchronous manner.

The first step in making synthetic diamonds involves putting graphite; a metal solvent, such as tantalum; and a catalyst, such as iron sulfide, into a tungsten carbide or ceramic chamber. The chamber is placed in the center of the press apparatus, where the sample is compressed by engaging the piston press members. The temperature of the sample is increased by passing electrical current through a heating tube into the tantalum. As the conical pistons advance, required pressures of about 55,000 atmospheres (more than 780,000 pounds per square inch) are generated. Temperatures may climb as high as 2,000° Celsius. After several hours, the graphite is converted into diamond, which is chemically identical to natural diamond and exhibits the same fundamental properties.

Synthetic diamonds differ from natural diamonds in those characteristics that depend on the process of manufacture, such as impurities, size, and shape. Synthetic diamonds in highest demand are made in grit sizes (approximately 0.1 millimeter in diameter) and are used for the manufacture of bonded diamond grinding wheels used for shaping and sharpening tungsten carbide tools. Synthetic diamonds are superior to natural diamond for this use because they are single crystals that have many cutting edges. A number of large synthetic diamonds of gem quality have been made by slow growth of diamond from high-purity carbon dissolved in a molten iron-nickel alloy, a process known as chemical vapor deposition (CVD). However, the majority of synthetic diamonds are imitation diamonds made from yttrium-aluminum garnet or strontium titanate.

struments made dental work safer, faster, cheaper, and less painful and allowed eyeglasses to be made in an hour or less. In place of using jackhammers, saws made with synthetic diamond blades became the primary tool used for repairing roads.

In 1970, Hall received the Chemical Pioneers Award from the American Institute of Chemists. Two years later, he was presented the American Chemical Society Award for Creative Invention for being the first scientist to invent a reproducible process for manufacturing synthetic diamond. In 1994, Hall was awarded the Governor's Medal for Science and Technology.

—*Alvin K. Benson*

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See also: Edward Goodrich Acheson; Dorothy Crowfoot Hodgkin.

JAMES HARGREAVES

English machinist

By inventing the spinning jenny, Hargreaves produced one of the earliest devices that led to the industrialization of the textile industry, and thereby to the Industrial Revolution in the Western world.

Born: January 8, 1720 (baptized); Oswaldtwistle, Lancashire, England
Died: April 22, 1778; Nottingham, England
Also known as: James Hargraves
Primary field: Manufacturing
Primary invention: Spinning jenny

EARLY LIFE

Little is known about the early life of James Hargreaves (HAWR-greevz), except that by the 1740's he was working as both a weaver and a carpenter and was for a while employed by Robert Peel, grandfather of the later prime minister of England. Peel was a small-scale manufacturer of textiles, and he employed Hargreaves to help build a machine that could be used to card raw fiber, especially cotton, to prepare the fiber for spinning into thread and weaving into cloth.

LIFE'S WORK

Hargreaves's efforts on behalf of Peel led him to develop the spinning jenny, and it is possible that his work on the machine to card raw cotton contributed to his idea. His model is said to have been a spinning wheel that was knocked over by his daughter Jenny but continued to spin, suggesting that a machine in which the action was aligned horizontally instead of vertically as in a spinning wheel inspired his invention. He built several machines in accordance with this conception, the earliest reportedly in 1766, and Peel is thought to have told Hargreaves that if he did not make his idea known, Peel himself would see to it. In response to this argument, Hargreaves is said to have sold several of his jennies to others working in the textile field.

Word soon got out about the new machine, however, and a mob composed of those who drew their livelihood from the old-fashioned spinning wheel looted Hargreaves's home and workshop and then burned them. Hargreaves responded to this assault on his work by switching for a short time to bookkeeping, also for Robert Peel. In 1770, Hargreaves moved from Oldtwistle to Nottingham and there resumed his work on the jenny. At that point, he decided to seek a patent for his invention. Although initially he was granted one, the patent was invalidated when it became known that he had sold early versions of the jenny to others before submitting his application. Hargreaves died in Nottingham in 1778 and appears to have amassed a modest estate prior to his death. Attempts by his widow to resuscitate the patent failed.

THE SPINNING JENNY

Converting loose fiber to yarn, so that it could be woven in a loom, involved both stretching it out and twisting it, initially using the fingers of the spinner. Hargreaves's invention, building on ideas floating around the textile field at the time, involved using synchronized rollers to replace the twisting fingers of the spinner. The process actually began with carding, which aligned all the fibers in the same direction. Then several strands of fiber were brought together in what was called the roving, which was wound on a spindle. Hargreaves's machine mounted several spindles of roving together and aligned them so that they could pass through two adjacent rollers, which were themselves set in motion. Improved models had the rollers turning in opposite directions, which enhanced the tightness of the yarn, and others replaced the driving wheel (which gave motion to the spindles and rollers) with one that was vertical, rather than the initial horizontal wheel.

The early jennies were made of wood, at least for the frame. The rollers had to be made of metal, however, so that they could be placed immediately next to one another to ensure that as they turned in opposite directions, they would add the desired twist to the yarn. As Hargreaves initially imagined his jenny, it converted the roving to just four strands of yarn. With improvements, the number of spindles rapidly increased, so that output was magnified by much more than the initial factor of four. Nevertheless, in its conception the jenny retained a basic simplicity such that it could be operated even by children, a circumstance that may have led to the employment of children in textile mills, especially in the early nineteenth century.

The earliest output of the jenny made yarn corresponding to the later density of twenty, which meant that it could not be used for the warp thread, the thread that was set up initially on the loom and against which the weft thread would be pushed. Rapid improvements in the quality of the jenny and the upgrading that followed, however, led to the production, by the early nineteenth century, of yarn that was suitable for both the warp and the weft.

IMPACT

Hargreaves's spinning jenny, and subsequent modifications of it, offered a response to a need. John Kay's invention of the flying shuttle in 1733 had already sped up the weaving process, so that a shortage of yarn soon emerged. The jenny aided in the handicraft production of textile materials that was the prevailing mode at the time. It could be operated by a single individual and was readily transportable, so that it could be set up in the home of the workman. The jenny initially increased by a factor of four the amount of spun yarn that a single workman could produce. A somewhat similar invention by Sir Richard Arkwright, called the spinning or water frame, also spread rapidly around the textile districts of England. Arkwright's machine was bigger, heavier, and required more force to operate, however, so that it was ill-suited to use in the home.

The last half of the eighteenth century, between 1750 and 1800, were years when the world of work was transformed by technological innovation. During this period, the task of spinning yarn from fibers was converted from handwork to machine work, and the spinning jenny was an important step in this process. Because it was really an amplification of the spinning wheel, the jenny had one foot in the old world of craft production and one in the new, foreshadowing how creating textiles in massive quantities would bring into being the industrial world.

Concurrently with the production of new textile machinery was the introduction of the new fiber cotton. Hitherto most European cloth had been made from wool or flax, both of which could be easily produced agriculturally in northern Europe. Cotton cloth, made with fiber from India (a small amount came from Egypt) was a luxury product in the early to mid-eighteenth century. Indeed, some Indian cloths, known as calicoes, had been for some time imported into Europe and worn by the upper classes. As the population expanded in the eighteenth century, however, the need arose for more cotton, especially as the demand grew for underclothing made of cotton cloth. The serendipitous discovery that cotton could be grown in more places, especially the southern region of the United States, and the invention of the cotton gin in 1793 by the American inventor Eli Whitney made possible cotton production on a large scale.

Hargreaves's invention of the spinning jenny was one in a string of new inventions that made the cotton textile industry of Britain the opening phase of the Industrial Revolution. Britain's imports of cotton rose from three metric tons in 1780 to twenty-four metric tons in 1800 and fifty-six in 1810, a growth made possible only as the new textile machinery took over.

—*Nancy M. Gordon*

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See also: Sir Richard Arkwright; Edmund Cartwright; John Kay; Sakichi Toyoda; James Watt; Eli Whitney.

SIR JOHN HARINGTON

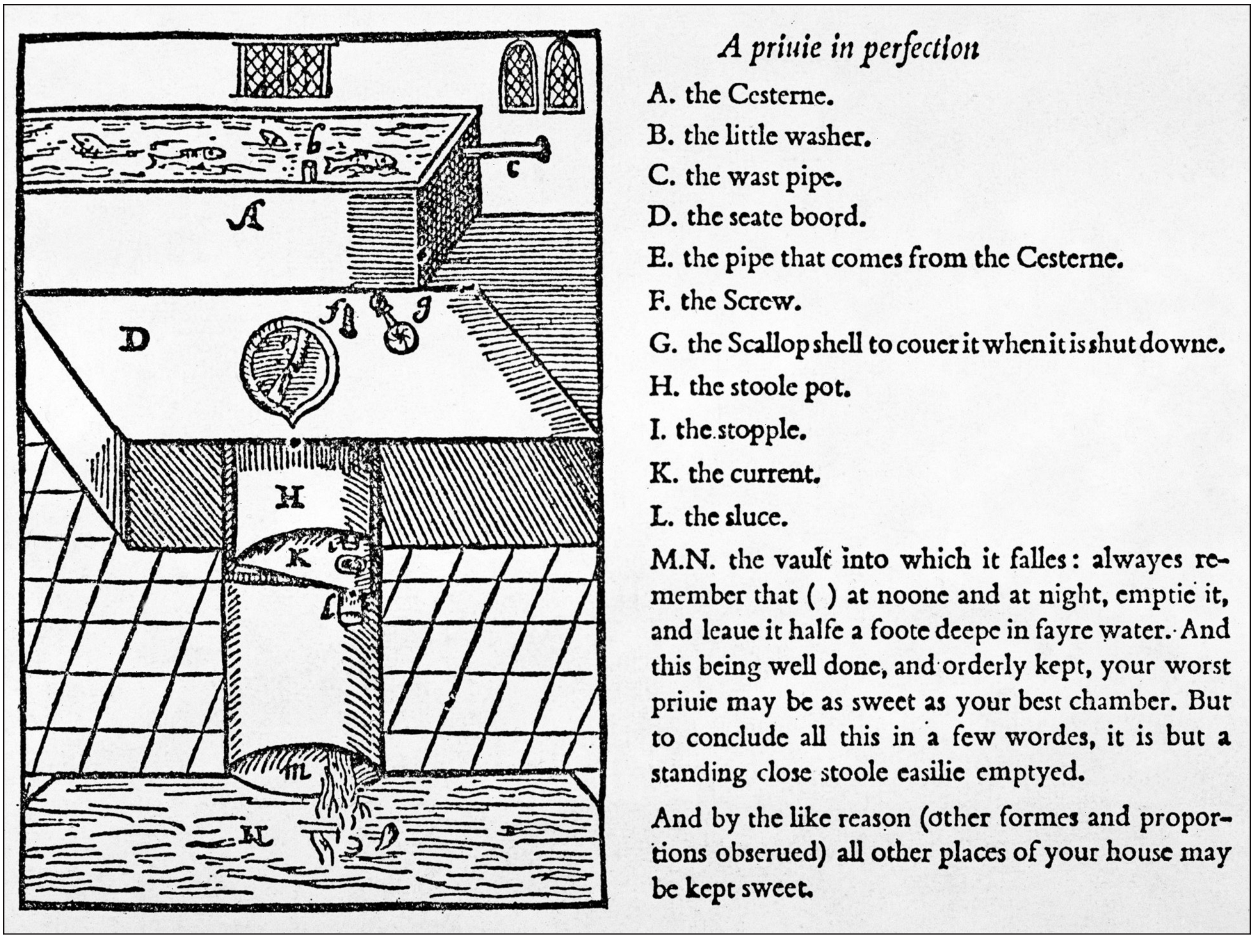
English author and translator

Known primarily as a literary man in the time of Queen Elizabeth I, Harington perhaps succeeded most practically as the inventor of the flush toilet, which he described in considerable detail in a work published in 1596.

Born: 1561; Kelston, Somerset, England
Died: November 20, 1612; Kelston, Somerset, England
Primary field: Plumbing
Primary invention: Flush toilet

EARLY LIFE

Sir John Harington was accorded the advantages of being an early Elizabethan gentleman because his father, John Harington of Stepney, married Etheldreda Malte, a prominent person who was actually a natural child of King Henry VIII. Queen Elizabeth I served as his godmother. He thus was able to obtain an education at Eton and King's College at Cambridge, where he took his degree about 1578. Higher education at that time was based heavily on the acquisition of ancient Greek and Roman culture, but by this time he was exposed to scholars who



A priuie in perfection

A. the Cesterne.
B. the little washer.
C. the wast pipe.
D. the seate boord.
E. the pipe that comes from the Cesterne.
F. the Screw.
G. the Scallop shell to couer it when it is ſhut downe.
H. the stoole pot.
I. the stopple.
K. the current.
L. the ſluce.
M.N. the vault into which it falles: alwayes remember that ( ) at noone and at night, emptie it, and leaue it halfe a foote deepe in fayre water. And this being well done, and orderly kept, your worst priuie may be as sweet as your best chamber. But to conclude all this in a few wordes, it is but a standing close stoole easilie emptyed.

And by the like reason (other formes and proportions obserued) all other places of your house may be kept sweet.

The design for Sir John Harington's flush toilet, here called "a privie in perfection." (The Granger Collection, New York)

also had a reputation as Renaissance humanists familiar with the work of learned Frenchmen and Italians of the fourteenth through sixteenth centuries.

Harington earned his master's degree in 1581 and then took residence at Lincoln's Inn, where lawyers and prospective lawyers studied and articulated law. In effect, an inn of court such as Lincoln's Inn also served men like Harington who had only an incipient interest in the law but were interested in extending their learning and establishing helpful contacts with educated men. At his father's death in 1582, he separated from Lincoln's Inn. In 1583, he married Mary Rogers, with whom he eventually became the father of eleven children, seven of whom survived him.

Life's Work

Although it may seem curious to associate Harington's invention of the flush toilet with his career as a poet and a translator, humanist scholars at the time actually did literary work that could encompass topics such as social ills, religious intolerance, and other issues seemingly remote from the interests of literary men. One of Harington's interests, cleanliness, he shared with other socially prominent people in a society pervaded by deplorable sanitary conditions. By modern standards, no one in his time washed regularly, garbage and human wastes were routinely emptied into gutters or any handy minor waterway, animals browsed in the streets, and people endured many sorts of environmental pollution. Nevertheless, a gentleman like Harington at least hoped to make his household as sweet smelling as possible. He later displayed his interest in sanitation in his translation of *Regimen sanitatis Salernitanum*, a work from the twelfth or thirteenth century known as "The Medical Poem of Salerno."

A Renaissance humanist characteristically hoped to learn from the people, real and legendary, of classical antiquity. Thus, Harington described his invention of the flush toilet in a work that bore the curious title of *A New Discourse of a Stale Subject, Called the Metamorphosis of Ajax* (1596). Here the word "stale" refers to something that loses freshness or is uninteresting. Humanists also liked to argue that some seemingly uninteresting things might turn out to be interesting after all. Substantively, "stale" can also refer to urine. This play on words, even in a serious discussion, was a common rhetorical device in Harington's time. The reference to Ajax connects the activity of toilet manufacture with the Greek warrior who in the Trojan War was insulted by Odysseus and according to post-Homeric legend went off in a fit of anger to a field in which he slew himself. From the grasses that grew from his blood a young man, needing to wipe himself, took advantage of the grasses. To express his respect to Ajax, he built a fine privy and dedicated it to him. Thus, the English word "jakes" is still used to refer to a privy. The American word "john," named for Harington, refers to a toilet.

In some respects, Harington undercut the seriousness of his invention by writing in a somewhat joking style that doubtless led many readers to undervalue it. Partly, this habit is explained by the fact that Harington enjoyed a reputation as a wag; partly, it was attributable to an attitude toward style found in many Renaissance writers. To take one famous example, Sir Philip Sidney also could assume a jocular style or added bantering details that might deceive an audience unfamiliar with his situation, which was in many respects like Harington's. Both were Elizabethan courtiers, and as such they were supposed to cultivate an attitude that had been described for them by an Italian diplomat named Baldesar Castiglione in his book *Il cortegiano*, published in 1528. Translated into English in 1561, it is usually known today as *The Book of the Courtier*. The courtier must cultivate *sprezzatura*, which can be translated "nonchalance." A literary work should appear to have been done without effort and almost without thought. Sidney wrote an essay that he referred to as a "pitiful defence of poor poetry" and as an "ink-wasting toy of mine." It is actually one of the great works of literary criticism, and Sidney's self-criticisms cannot be taken seriously.

When the work at hand is a manual on how to make a toilet, Harington obviously needed plenty of *sprezzatura*. He would have read *Il cortegiano* in the original Italian, which he understood well, his best-known literary work today being his translation in nearly 33,000 lines of Ludovico Ariosto's famous romance *Orlando furioso*, published five years before Harington's *A New Discourse of a Stale Subject*.

Scholars today know Harington best for works that are today classified as literary. He, like Sidney, wrote an apology (a defense) of poetry as an introduction to his translation of *Orlando furioso*, and a considerable number of his letters and poems have survived. Because he was working in an era dominated by William Shakespeare and many other eminent writers, his writings have largely been ignored.

THE FLUSH TOILET

In his 1596 work *A New Discourse of a Stale Subject, Called the Metamorphosis of Ajax*, Sir John Harington recommended that the flush toilet be installed in such a place that had access to the chimney to take advantage of the wind's capacity to blow off unpleasant odors. He noted that sometimes the operation of the chimney vent failed because of the lack of suitable wind. His invention required the establishment of a cistern, which could be located behind the toilet seat or elsewhere if necessary. Water would be brought from the cistern in a lead pipe controlled by a tap that would "yield water with some pretty strength."

An oval pot of block, stone, or lead, two feet deep, one foot broad, and sixteen inches long (Harington is normally very precise in his measurements) would be placed close to the seat and dressed with pitch or resin to keep the pot from "tainting with the urine." In the lowest part of this vessel there would be fastened a sluice of brass with solder or cement. On this sluice would be an iron stem with a stopper fastened with a strong screw. Harington's practicality is also reflected in his recommending a lock and key to keep children from playing with this device. No air should be allowed to come up except at the sluice, which has the stopper. The water, which could be pumped into this place, could be used more than once but had to be changed when necessary, which he suggested should be at noon or at night, not through any such venting system as exists today.

If constructed carefully, this device would, he said, keep the privy "as sweet as your best chamber." Clearly, a servant would have been necessary to serve the device and perform a task that in later times would be performed by connection to a seepage pit or a sewer. Queen Elizabeth I installed a flush toilet in at least one of her palaces, and Harington made a toilet for himself. Apparently both used their toilets, but there is no record that any others in his time used one.

After the queen's death in 1602, Harington made efforts to win the favor of the court but did not receive the promotion he sought. He became ill in May of 1612 and died in Kelston that November.

IMPACT

For centuries, Harington's device had no traceable impact. Some people presumably did not share Harington's daintiness about smells; others surely doubted that the advantages of a water-driven system of coping with human wastes justified systematic efforts to bring about this change. The great majority of people lived in small communities or on farms, and such wastes were easily enough disposed of. However, a general unfamiliarity with the literary habits of a man like Harington probably also curtailed the spread of information about his invention.

As a result, the impact of Harington's toilet was very limited until later needs and improvements made it a practical device for people who did not employ servants to assist them in fulfilling their personal needs. Not until the eighteenth century were there any patents for toilets. In the 1770's, several men made contributions. Alexander Cummings developed the S-trap between bowl and trap, Samuel Prosser patented a plunger closet, and Joseph Brahmah devised a valve for the flushing system that worked on a hinge. This was a predecessor to the ballcock that is still often used today.

A series of refinements in the design of the flushing closet from the 1850's to the 1890's made the flush toilet a possession for many householders. The growth of large and densely packed cities in the later nineteenth century made safe and efficient plumbing systems necessary, and increasingly the toilet became a practicable addition to well-appointed households. The toilet that Harington devised did not replace the old privy, and for three centuries it did not become a common feature of life in European or American homes.

—Robert P. Ellis

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See also: Lewis Howard Latimer.

JOHN HARRISON

English engineer and clockmaker

Harrison developed chronometers that could keep time at sea with sufficient accuracy to make reliable calculations of longitude at any point on the globe. This development revolutionized maritime navigation.

Born: March, 1693; Foulby, Yorkshire, England
Died: March 24, 1776; London, England
Primary fields: Maritime technology; navigation
Primary invention: Sea chronometers

EARLY LIFE

John Harrison was born in March, 1693, in the village of Foulby in Yorkshire, England. While he was still a young child, the Harrisons moved to Barrow-on-Humber in Lincolnshire, where John apprenticed with his father to become a carpenter. He married Elizabeth Barrel in 1718, and when she died in 1724 he remarried to Elizabeth Scott. Interested in mechanics from the time he was a teen, Harrison began constructing clocks by 1713.

While carrying out his principal trade, for more than a decade Harrison and his younger brother James worked at perfecting an accurate regulator clock. Their partnership lasted nearly two decades.

Sometime after 1714, Harrison learned that an act of Parliament had established a prize of £20,000 to be awarded to the first person who could develop an accurate method of determining longitude, the east-west position of an object on Earth. This calculation was especially important to ships, which had often missed ports of call or suffered tragedies because they could not determine accurately their location on the open oceans. The act creating the Longitude Prize also established a Board of Longitude to evaluate any proposal or machine submitted by claimants, and it specified terms for the award of any or all of the amount set aside by Parliament. Sometime during the 1720's, Harrison decided to compete for the prize.

After a decade of experimentation, in 1730 Harrison published a lengthy treatise describing his method for crafting a "sea clock" for use in calculating longitude by comparing the local time to the time at a fixed point of departure. While the method made sense theoretically, few thought it possible to construct a device that would keep accurate time under the harsh conditions at sea. Harrison disagreed. He proposed an innovative design that reduced fluctuations due to friction, compensated for changes in temperature, and adjusted for fluctuations in the speed at which a clock might run when first wound or when in need of rewinding. Confident in his ability, in 1730 he applied to the Longitude Board for funds to construct his first sea clock. Some members were immediately interested, and they obtained financial support for him. Harrison spent the next five years building a machine that he could submit to the trials specified for earning the prize.

LIFE'S WORK

Harrison's challenge was significant. He was operating on the principle that longitude could be calculated by comparing the difference between local time and the time at the ship's point of departure. Although local time could be measured at sea using astronomical readings, knowing the time at one's departure point had always been difficult to determine because even the best timepieces lost seconds (sometimes minutes) each day. Errors of seconds or minutes could result in inaccuracies placing a ship many miles from its actual location. Therefore, the design of a clock that could withstand the rigors of sea travel and keep time with sufficient accuracy was key to solving the problems associated with determining longitude.

The first sea clock designed by Harrison with the assistance of his brother, designated H1 by later historians, was a bulky chronometer measuring three feet in height, width, and depth, consisting of various metals and wood. After inspection by members of the Royal Society of London, the country's leading scientific organization, it was given a short sea trial to Lisbon, Portugal, in 1736. The terms of the act of Parliament establishing the prize, however, specified that the device must be proven accurate on a round-trip voyage to the West Indies. In 1737, the full Board of Longitude met to examine H1 and review results from the Lisbon voyage before authorizing the West Indies test. Curiously, rather than submit H1 to the West Indies voyage, Harrison indicated that he wished to construct a new clock for this test, and with the board's financial support he began crafting H2, incorporating improvements of original concepts used to build H1. Two years later, Harrison decided to shelve H2 and begin work on H3. For the next nineteen years, he worked diligently on the project. During this time, he received small sums from the Longitude Board to underwrite his work. Additionally, even though none of Harrison's clocks had yet been tested under the terms established for the award of the Longitude Prize, in 1749 Harrison's accomplishments were celebrated publicly when the Royal Society presented him with the Copley Medal, its highest honor.

While Harrison was working to perfect H3, he was also experimenting with the design of watches. Although there were similarities between the two forms of timepieces, the construction of an accurate watch required even more skill. Harrison manufactured a pocket watch in 1753 and, perhaps encouraged by its accuracy, began constructing a larger one for use at sea. Harrison was now working closely with his son William, who eventually became his spokesperson and public champion. By 1760, Harrison had completed work on H3, which was scheduled to be tested on a voyage to the West Indies, but for some reason Harrison decided to submit to the Longitude Board his new watch, designated H4, for testing. Because he was too old for extended sea travel, Harrison sent William on the voyage to Jamaica, during which the watch proved remarkably accurate. Unfortunately, when the board met in 1762 to review the results, questions arose about testing procedures and Harrison was denied the prize. Instead, over the next several years the board established new criteria Harrison would have to meet in order to claim the £20,000.

Harrison was furious, and he blamed his fate on machinations by certain board members, particularly Nevil

Maskelyne, who in 1762 was working on an alternative method for calculating longitude using lunar charts, and who eventually assumed the influential post of astronomer royal. Maskelyne was not alone in expressing concern about Harrison's work. Many board members were insistent that Harrison turn over all of his timepieces to them and agree to let others reproduce his chronometers so that the board could determine if his solution was practical. Harrison was hesitant to comply with these directives. By 1763, rivals began to emerge to compete for the prize, and he was concerned that his work might be pirated.

A second sea trial of H4 was authorized, and even though Maskelyne was heavily involved in it, the results were sufficiently promising for the board to award Harrison half the prize, indicating that he could qualify for the other half if the watch passed further tests—and if it could be shown that his chronometer was replicable. Harrison was not content with the decision, which he thought was politically motivated. After fighting for years to keep his designs secret, in 1767 he finally acquiesced to the board's demands, turning over his four devices and his technical drawings to them. The board commissioned a rival watchmaker, Larcum Kendall, to construct a duplicate of H4. Further trials of Harrison's watch were held at the Royal Observatory in Greenwich. Harrison was also instructed to make two duplicates, but he delayed that work for a variety of reasons, instead concentrating his efforts on construction of yet another timepiece, H5. By this time, King George III had begun to show a personal interest in Harrison's work, and a test of the H5 was conducted at the king's personal observatory in Richmond outside London.

While they continued wrangling with the Longitude Board, both John and William Harrison mounted a public campaign to gain the remainder of the prize money, lobbying Parliament for redress. In 1773, at the urging of the king, Parliament agreed to award Harrison £8,750—not the full amount he had hoped for, but a sum that clearly indicated the nation's gratitude for his accomplishments. Although Harrison felt only partially vindicated by this grant, he was finally satisfied that he was being recognized as the person who had solved "the longitude problem." He died in 1776 before mass production of maritime chronometers based on his designs would revolutionize shipping throughout the world.

IMPACT

Harrison's chronometers proved that it was possible to create a device that could keep time at sea with sufficient accuracy to make reliable calculations of longitude at any point on the globe. His combination of specially designed balances, his employment of a bimetallic strip to compensate for expansion of metals at different temperatures, and his development of a mechanism to ensure that time was kept accurately while his chronometers were being rewound were revolutionary ideas that paved the way for the production of chronometers that would allow ships to sail with greater assurance of their position.

HARRISON'S SEA CLOCKS

During his lifetime, John Harrison created five timepieces designed to aid in the calculation of longitude at sea. While their external shape and size varied greatly, they shared common characteristics that made them radically different from earlier clocks and watches, largely because their internal mechanisms compensated for a number of technical difficulties that interfered with the ability of a mechanical timekeeper to function regularly. Among these were problems of friction, damage from natural elements (especially changes in temperature), and irregularities caused by the use of a metal spring that must be wound.

By the time Harrison came to design H4, a watch measuring 5.5 inches in diameter, he had managed to find solutions for most of these problems. When developing his larger clocks, he had perfected a system of balances that replaced the conventional pendulum, which had to be maintained in an upright position to work accurately. The new balances permitted the clock to continue to operate accurately regardless of its position, an important innovation since the rocking motion of a ship at sea made it impossible to keep the clock vertical at all times. In creating H4, Harrison transferred this idea to a set of balances that functioned in a similar fashion inside the smaller device. He solved the problem caused by the expansion and contraction of metal parts by developing a bimetallic strip, which helped regulate the movement of the watch. Because the two metals expand and contract at different rates in different temperatures, one counteracts the other; this allowed the watch to keep time accurately despite fluctuations in temperature. Harrison also developed a mechanism for transferring the power of the mainspring, which could fluctuate as it gradually lost tension after being wound, through a secondary spring that was constantly rewound so that it applied a constant force to the movement of the clock's hands.

The first real vindication for Harrison's efforts was accomplished before he died. Captain James Cook departed England in 1772 for a South Seas voyage, taking along the copy of Harrison's chronometer made by Kendall. As Cook reported, that device proved exceptionally valuable for determining longitude and charting the lands visited by him in his three-year cruise. While many improvements were made in the decades following Harrison's death, several devices modeled on his designs were constructed for general use. Not only did these provide a means of calculating a ship's position, but, as Cook had shown on his voyage, they also were instrumental in helping mariners revise charts of the ocean and its land masses, especially islands located at remote places around the world. As a consequence, the work Harrison did in developing his sea clocks paved the way for the expansion of both commercial trade and exploration that occurred during the nineteenth century and beyond.

—*Laurence W. Mazzeno*

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See also: John Campbell; Martha J. Coston; Robert Hooke.

OLIVER HEAVISIDE

English mathematician, physicist, and electrical engineer

Heaviside invented the distortionless transmission line for telegraph and telephone cables. He also invented operational calculus and vector calculus, using the latter to simplify James Clerk Maxwell's electromagnetic field equations to their modern form.

Born: May 18, 1850; London, England
Died: February 3, 1925; Torquay, Devon, England
Primary fields: Communications; electronics and electrical engineering; mathematics; physics
Primary inventions: Distortionless transmission lines; operational calculus

EARLY LIFE

Oliver Heaviside (HEHV-ee-sid) was born on May 18, 1850, in London, England. His father was Thomas Heaviside, a watercolorist and engraver, and his mother was Rachel Elizabeth West, whose brother-in-law was Sir Charles Wheatstone, coinventor of the telegraph in the 1830's. Oliver was born in the slums of London and suffered from scarlet fever as a child, which left him partially deaf and unable to relate easily with other children. Although he was a good student, he left school at age sixteen to study at home, concentrating for two years on telegraphy, electromagnetism, and the study of German and Danish.

At the age of eighteen, with assistance from his famous uncle, Heaviside began his first and only paid job as a telegraph operator with the Great Northern Telegraph Company, beginning in Denmark in 1868. Three years later, he was transferred by the company back to England at its office dealing with overseas traffic in Newcastle upon Tyne, where he became a chief operator. During his six years of employment, he published two papers on electric circuits and telegraphy (in 1872 and 1873), which interested the Scottish physicist James Clerk Maxwell enough to mention them in the second edition of his *Treatise on Electricity and Magnetism* (1873).

Heaviside became so fascinated with Maxwell's treatise that he gave up his job in 1874 at the age of twenty-four and returned to his parents' home in London to devote himself full-time to studying it and learning the requisite advanced mathematics. During this time, he grew increasingly deaf and reclusive, remaining single all of his life. After several years, he had mastered Maxwell's electromagnetic theory and its associated mathematics before setting it aside to develop his own ideas, including the invention of new forms of mathematics to recast Maxwell's equations in their modern vector form.

LIFE'S WORK

Oliver Heaviside began his research in 1880 on the skin effect in telegraph transmission lines that increased the resistance near the center of the lines with increasing frequency and concentrated the current flow near the surface, or "skin," of the conductors. In 1880, he patented the coaxial cable as a way to transmit high-frequency signals more efficiently. He was able to apply Maxwell's equations to the skin-effect problem and solved them for conductors of any shape, showing how the current was distributed and how resistance increased with frequency because of eddy currents induced by the changing magnetism caused by rapidly alternating current. He published this work in 1885 in a paper on "Electromagnetic Induction and its Propagation" in *The Electrician*.

In the course of his electrical research, Heaviside began to adapt complex numbers to the theory of electric circuits. In this work, he introduced the Heaviside step function to aid in mathematical modeling of circuits. He also independently formulated vector analysis along lines similar to the work of Josiah Willard Gibbs in the United States, and he invented an operational form of calculus for solving linear differential equations by transforming them into algebraic equations. His mathematical work led to controversy because he did not apply rigorous methods to the derivation of his results, viewing them as pragmatic and experimental. Nevertheless, this work became the basis for much of electrical engineering in the twentieth century and provided the key to his success in reformulating Maxwell's equations in a simpler form and obtaining solutions from them.

In 1884, Heaviside applied his new ideas of vector analysis to electromagnetic theory. Maxwell's original equations linking electric and magnetic fields were extremely cumbersome, requiring twenty equations in twenty variables representing the sources and spatial components of the fields. With the use of vector notation and the vector calculus operators he had invented, Heaviside reduced Maxwell's equations to just four elegant vector equations in two variables, emphasizing the basic symmetries between electric and magnetic fields. Two of these equations derive from Gauss's law and describe the source and structure of electric and magnetic

DISTORTIONLESS TRANSMISSION LINES

Although Oliver Heaviside began his career as a telegraph operator, he spent much of his time thinking about the theory of telegraph circuits and cables. His earliest papers of 1872 and 1873, before his retirement in 1874, already reveal his ingenuity on these topics. His second paper introduced his duplex telegraph invention, which allowed telegraph signals to be sent both ways on a telegraph cable at the same time without interfering with each other, eliminating the need for two separate cables. The key to this invention was the application of his uncle's invention of the Wheatstone bridge to telegraph cables, which he used at both ends of the line. By properly arranging the resistances of the bridge circuits and the connecting telegraph cable, he could assure that the receivers placed in the bridge would be isolated from the sending signals.

A general transmission-line theory was developed by Lord Kelvin in 1855, using a diffusion model for the current in a submarine cable, including the effects of resistance and capacitance. Kelvin's model correctly predicted the poor performance of the first trans-Atlantic submarine cable, completed in 1858, which could transmit only about one-tenth of a word per minute and operated for just one month before technical mistakes led to its demise. A second improved cable was completed in 1866, but still was limited to about eight words per minute. This problem led to considerable distortion in telephone messages when they began to be used in the 1880's. Heaviside began to analyze this problem after deriving his telegrapher's equations in 1885 from James Clerk Maxwell's equations.

The telegrapher's equations generalized Kelvin's equation with the inclusion of inductance, thus going beyond mere diffusion effects and accounting for the kind of wave propagation involved at the higher frequencies of telephone signals. After a careful analysis, Heaviside published the conditions for distortion-free signaling in 1887 and showed that adding the right amount of inductance along the transmission line would reduce and equalize the attenuation of currents at all frequencies. Unfortunately, his suggestion of adding induction coils along the line was rejected by William Preece, engineer in chief of the British General Post Office. Thus, the development of trans-Atlantic telephony was delayed for nearly twenty years until Heaviside's ideas were revived in 1904 by Michael Pupin and AT&T.

fields. The other two equations generalize Ampere's current law and Faraday's voltage law to show how changing electric fields produce magnetic fields and changing magnetic fields produce electric fields. For several years, these vector forms of Maxwell's equations were called the Heaviside-Hertz equations because Heinrich Hertz was the first to apply them in his discovery of radio waves.

In 1885, Heaviside applied Maxwell's equations to electrical transmission lines to obtain the modern form of the telegrapher's equations. He applied these equations to the trans-Atlantic submarine telegraph cable, which suffered from distortion problems. In 1887, he recommended that induction coils be added to telephone and telegraph lines to correct this distortion. Unfortunately, his ideas were ignored for political reasons but were eventually adopted by the American Telephone and Telegraph Company (AT&T) based on a patent given to Michael Pupin in 1904. When AT&T later offered to purchase Heaviside's rights, he refused the money for lack of full recognition even though he had very little income. In 1891, he was elected as a fellow of the Royal Society.

In the 1890's, Heaviside became interested in the problem of the age of Earth, which had been calculated to be about 100 million years by Lord Kelvin some thirty years earlier by assuming uniform thermal conductivity in the cooling of the planet. This notion proved to be a great challenge to Charles Darwin, whose theory of evolution required several billion years. In 1894, Heaviside used his operational calculus to repeat Kelvin's calculation, but making the assumption of a change in thermal conductivity near the surface of Earth corresponding to its crust. This calculation led to a much older age of Earth, which could be on the order of billions of years depending on a range of values for the heat constants.

At the age of forty-seven, after his parents had died, Heaviside began living by himself for the first time in his life. Friends arranged for him to receive a civil list pension of 120 pounds per year as a government-recognized authority. In 1897, he left London and moved to a house in Newton Abbott a few miles from Paignton, Devon, in the southwest corner of England, with an elderly lady as a servant. One of his last scientific contributions was an explanation for Guglielmo Marconi's success in transmitting radio waves across the Atlantic Ocean over the curvature of Earth. In 1902, Heaviside proposed the existence of a charged layer in the upper atmosphere, now known as the Kennelly-Heaviside layer of the ionosphere, which transmits radio waves by reflection between it and Earth's surface. In 1908, he moved to Torquay in Devon, where he lived his last years as a virtual hermit.

IMPACT

The main impact of Heaviside's work came from the mathematical techniques he invented and their applications in electromagnetic theory. He used these techniques to simplify Maxwell's electromagnetic equations and applied them to a wide range of transmission-line problems. His independent invention of vector analysis, including the divergence and curl operators of vector calculus, made it possible to reduce the twenty equations of Maxwell's electromagnetic field theory to their modern form of just four compact and symmetric equations. It was this form of Maxwell's equations that led Heinrich Hertz to his 1887 discovery of radio waves. Heaviside's invention of operational calculus, similar to the method of Laplace transforms that largely replaced it after 1937, led him to many important solutions of Maxwell's equations. These mathematical techniques have had wide applications in many areas of engineering and physics since their invention.

Heaviside's work is especially important for his innovations in electrical engineering, including the complex-number analysis of electric circuits and the invention of the telegrapher's equation. He introduced much of the modern terminology of alternating-current circuit analysis, including such terms as conductance, permeability, inductance, impedance, admittance, reactance, and reluctance. His derivation of the telegrapher's equation to analyze transmission lines led him to recommend adding induction coils, which made it possible to have distortion-free transmission over long-distance cables for a wide range of frequencies as required in modern telephone communications. One of his final contributions was the publication of his three-volume *Electromagnetic Theory* (1950), summarizing and extending much of his life's work.

—*Joseph L. Spradley*

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Heinrich Hertz, Oliver Lodge, and George F. Fitzgerald.

Lee, George. *Oliver Heaviside and the Mathematical Theory of Communications*. London: Longmans, Green, 1947. This thirty-two-page monograph prepared for the British Council describes the works of Heaviside.

Nahin, Paul J. *Oliver Heaviside: Sage in Solitude—The Life, Work, and Times of an Electrical Genius of the Victorian Age*. Baltimore: The Johns Hopkins University Press, 2002. This definitive biography includes many photos, sketches, and descriptions of Heaviside's mathematical work.

Searle, George F. C. *Oliver Heaviside, the Man*. St. Albans, England: C.A.M., 1987. This reprint of a 1950 centenary volume is edited by one of the last living friends of Heaviside, who also knew Hertz and Maxwell.

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See also: Michael Faraday; Joseph Henry; Heinrich Hertz; Lord Kelvin; Gottfried Wilhelm Leibniz; Guglielmo Marconi; Nikola Tesla; Charles Wheatstone.

HERMANN VON HELMHOLTZ

German physicist and physician

Helmholtz invented the ophthalmoscope for seeing into the interior of the eye and the ophthalmometer for measuring the curvature of the eyeball. He made major contributions to the physiology of seeing and hearing and established the modern theory of conservation of energy.

Born: August 31, 1821; Potsdam, Prussia (now in Germany)
Died: September 8, 1894; Charlottenburg, Berlin, Germany
Also known as: Hermann Ludwig Ferdinand von Helmholtz (full name)
Primary fields: Medicine and medical technology; optics; physics
Primary inventions: Ophthalmoscope; ophthalmometer

EARLY LIFE

Hermann von Helmholtz (HUR-mahn fahn HEHLM-hohltz} was born in Potsdam, Prussia (now in Germany) on August 31, 1821, to August Ferdinand Julius Helmholtz and his wife, Caroline Penn. His father was educated in philology and philosophy and became a teacher at Potsdam Gymnasium. Hermann was a sickly child and was kept home until he was seven years old. He amused himself with blocks and taught himself many things about geometry. His health improved when he was seven, and he was sent to Potsdam Gymnasium, where he amazed his teachers by what he had learned while at home.

His father's interest in philosophy, art, and music had a strong influence on Helmholtz, but after an introduction to physics in the *Gymnasium*, he decided he wanted to be a physicist. His father did not have the money to pay for his further education but found an army scholarship that paid for four years of education at a Prussian army medical institute of the University of Berlin in return for eight years of service in the army as a medical officer. At the institute, he studied under Johannes Müller, who was laying the groundwork for the physics of biology, now called biophysics.

After Helmholtz graduated, he spent two years as a surgeon in the Charité Hospital in Berlin but did not enjoy that assignment because of the hopeless cases he encountered. The remainder of his army service was spent in Potsdam, where he found the time to study further and publish several scientific papers, including his groundbreaking work on the conservation of energy.

LIFE'S WORK

Helmholtz's first publication was his thesis on the structure of the nervous system in invertebrates. After he graduated and did his required hospital service, he used his evenings and off-duty hours in Potsdam to study the action of muscles and the heat generated by them. He found that as chemical energy was translated into mechanical work and heat, the total energy within the system remained constant. Although Julius von Meyer and James Joule had made similar observations, Helmholtz's mathematical approach clarified the subject for the first time. His publication on conservation of energy in 1847 established his reputation as a first-rate scientist.

THE OPHTHALMOSCOPE AND OPHTHALMOMETER

The two great inventions of Hermann von Helmholtz are the ophthalmoscope for seeing into the internal structure of the eye and the ophthalmometer for measuring the curvature of the cornea. Together these have become primary tools of ophthalmologists and optometrists.

In 1850, Helmholtz built the first ophthalmoscope to illustrate the physiology of the eye for his students. It was a crude device consisting of a light source and microscope glass slides mounted on a handle at 45° to the eye and observer. The idea was to shine the light into the eye, where it would be reflected by the retina. Helmholtz knew that the light would follow the same path out as going in, so he reflected the outgoing light by 90° to his eye. Present-day ophthalmoscopes are more complex and often consist of a battery-operated light source and a concave mirror that focuses the light into the eye. The physician views the interior of the eye with lenses of different powers through a small aperture in the mirror.

Helmholtz invented the ophthalmometer in 1855 to measure the accommodation of the living eye to different focal distances. The ophthalmometer measures the reflection of objects in the convex surface of the cornea. These measurements determine, among other things, whether the cornea focuses on the lens or in front or behind it. If the focal point is not on the lens, the person is either nearsighted or farsighted. The amount and direction of astigmatism can also be measured by the degree to which the reflected image is displaced from the center of the front surface of the eye.

In his research, Helmholtz invented many other devices for the quantitative measure of the physiology of the eye and ear and the ability to perceive light and sound. As in all of his studies, his primary objective was to understand the fundamental mechanisms by which the eye and ear work.

Because of his obvious scientific talents, Helmholtz was released early from the army so he could take up an academic appointment as assistant at the Anatomical Museum and lecturer in the Academy of Fine Arts in Berlin. Within a year, he moved to the University of Königsberg, where he was appointed assistant professor and director of the Physiological Institute. He had gained worldwide fame with his 1847 paper on conservation of energy, so his rise in academia was spectacular. He spent six years at the University of Königsberg and then three years at the University of Bonn. During this period, his principal scientific work was on the physiology of vision and hearing. He also began his studies on the perception of light and sound.

While teaching at the University of Königsberg in 1850, Helmholtz prepared an experiment for his students to show that the light that enters the eye is partially reflected out, following the same path out as it had going in. He found that he could put his eye in the path of the reflected light and see the internal structure of the eye. He recognized that this would be important to physicians treating problems of the eye, so he publicized his findings, and the ophthalmoscope began to be manufactured. During the years between 1856 and 1867, Helmholtz published his mammoth reference work *Handbuch der physiologischen Optik* (*Handbook of Physiological Optics*). This has remained one of the most important works on the physiology and perception of seeing.

Helmholtz had become unhappy with his position at Bonn because of criticism from traditionalists in the university about his teaching of anatomy. He was teaching a new mechanical and physical approach that the older anatomy professors could not understand. In 1858, he accepted a professorship at the University of Heidelberg with the promise that the university would set up a new physiology institute for him. He did some of his most important work at Heidelberg. In 1863, he compiled his research on sound and published his famous book *Die Lehre von den Tonempfindungen als physiologische Grundlage für die Theorie der Musik* (*On the Sensations of Tone as a Physiological Basis for the Theory of Music*, 1877).

After Helmholtz completed the third volume of *Handbook of Physiological Optics* (1867), his research interests turned from physiology to physics. In 1870, the chair of physics at the University of Berlin became vacant, and Helmholtz, now one of the most famous scientists in the world, was offered the position. After negotiating a high salary and convincing Prussia to build a new physics institute to be under his control, he took up the chair in 1871. After his appointment, Helmholtz became interested in electricity and magnetism, attempting to derive the electrodynamic equations. He was unsuccessful in this, but after James Clerk Maxwell published his famous equations showing that changing electric and magnetic fields produce electromagnetic waves, Helmholtz's student, Heinrich Hertz, showed that these waves were real and measured the wavelength and reflection of the radiation. Helmholtz had many other doctoral students who made important discoveries in physics. Among these students were Albert Michelson, who with Edward Morley cast doubt on the ether theory, and Wilhelm Wien, who studied black-body radiation.

Because of his fame, Helmholtz was asked by different organizations to give popular lectures on science and on his discoveries. These lectures were later collected and published and became an important contribution to the understanding of science by the general public. Helmholtz received many honors during his lifetime, including the addition of the prefix "von" to his family name granted by Kaiser Wilhelm I in 1883. This honor was inheritable and was comparable to a knighthood.

Helmholtz was a "workaholic" and occasionally became ill from overwork. He had never completely recovered from his childhood sicknesses, and most of his life he had occasional migraine headaches and dizzy spells. In 1894, he fell and suffered a concussion from which he never recovered. He died of complications several months after his fall.

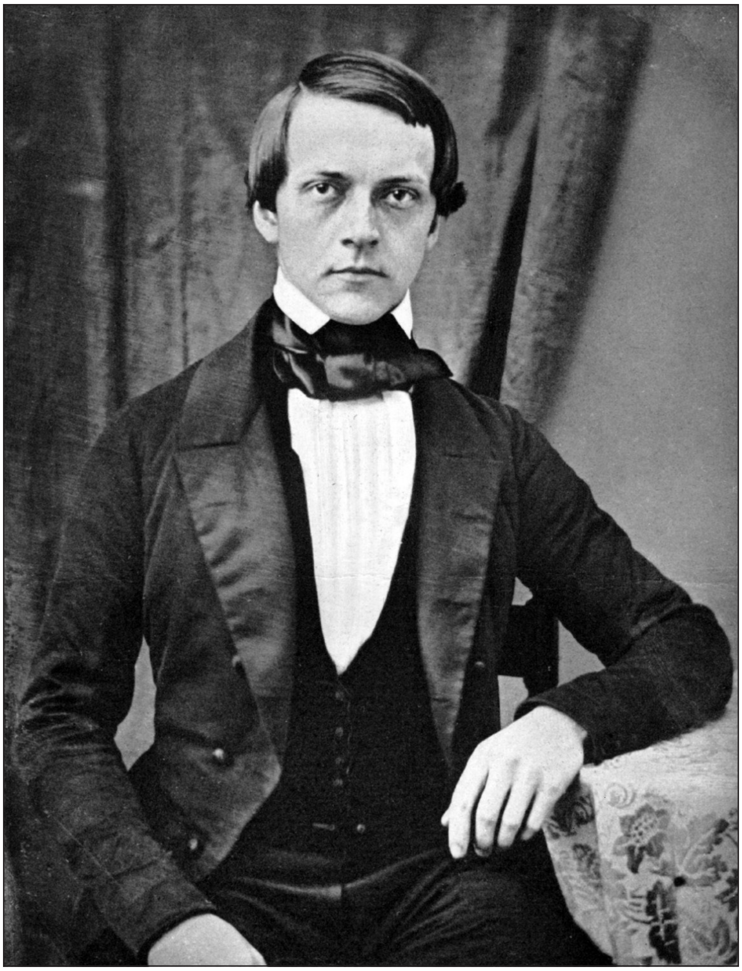
IMPACT

The primary unifying principle that bound together the life and work of Helmholtz was his belief that metaphysical ideas and vitalism were wrong and should be replaced by the laws of mathematics and physics. His philosophy guided his research, and from his earliest work on the conservation of energy to his final studies of electromagnetism and thermodynamics, he showed that nature could be understood in physical terms.

The tools that Helmholtz invented helped to establish the field of ophthalmology and are the main measuring devices for determining problems of vision. In addition, there are other diseases that have consequences for the eyes and that can be recognized by studying the eye. For example, the ophthalmoscope is used to examine retinal blood vessels, from which information can be obtained about high blood pressure and diabetes. The ophthalmometer can measure the ability of the eye to accommodate to situations such as different focal distances and can also measure astigmatism. Before the invention of the ophthalmoscope and the ophthalmometer, there were only limited means to determine the state of health of the eyes and what could be done to improve vision. Simple eyeglasses were available and could be fitted by trial and error, but many other vision problems could not even be recognized. With these two instruments, optometrists could design glasses to correct for defective vision.

From his studies in physiological optics, Helmholtz came up with a theory of three-color vision similar to that of the earlier scheme of Robert Young. This theory is now called the Helmholtz-Young theory of color vision and is important in understanding color blindness. Helmholtz was also interested in how the human ear perceived sounds. As an expert pianist, he wanted to know how pitch and tone were distinguished. He suggested that the inner ear could resonate at certain frequencies, enabling it to differentiate tones, overtones, and timbres—thus enabling the ear to distinguish different instruments playing the same note.

—Raymond D. Cooper



Hermann von Helmholtz. (Getty Images)

Further Reading

Cahan, David, ed. *Hermann von Helmholtz and the Foundations of Nineteenth-Century Science*. Berkeley: University of California Press, 1993. This book is based on a two-day conference in 1990 on Helmholtz as philosopher and scientist. It includes papers by fifteen historians of science and philosophy analyzing Helmholtz's contributions. Illustrations, chronology, index.

Helmholtz, Hermann. *On the Sensations of Tone as a Physiological Basis for the Theory of Music*. Whitefish, Mont.: Kessinger, 2005. This is a reprint of Helmholtz's book on classical acoustics. It includes the results of his research on the physiology of hearing, the relation of music to physics, and the perception of sound. He includes a discussion of the history of musical sound. Figures, tables, index.

_______. *Science and Culture: Popular and Philosophical Essays*. Edited and with an introduction by David Cahan. Chicago: University of Chicago Press, 1995. The introduction describes the life and scientific contributions of Helmholtz. This is followed by the full texts in English of fifteen of the scientific and philosophical lectures that he gave to popular audiences between 1853 and 1892. He discusses the theory of vision, physiological causes of harmony in music, and many other subjects. Selected further readings, index.

Koenigsberger, Leo. *Hermann Von Helmholtz*. Translated by Frances Alice Welby. Foreword by Lord Kelvin. New York: Dover, 1965. This is the most important biography of Helmholtz. It follows his life from his parent's home to his schooling and army service and then to his scientific research in a number of German universities. The book describes his contributions to the physiology of seeing and hearing and the physics of energy, mechanics, and electromagnetism. Illustrations.

McKendrick, John Gray. *Hermann Ludwig Ferdinand von Helmholtz*. New York: Longmans, Green, 1899. Lauds Helmholtz as one of the greatest scientific minds of the nineteenth century. Describes his life and character and his scientific achievements and discusses the background of the physical and physiological questions studied by Helmholtz, as well as the contributions and inventions he made toward their solutions. Bibliography, index.

See also: George Biddell Airy; Georg von Békésy; Alexander Graham Bell; Heinrich Hertz; Lord Kelvin; Gabriel Lippmann; Wilhelm Conrad Röntgen.

Beulah Louise Henry

American socialite

Henry is noted especially for the large number and the diversity of her inventions. She received forty-nine patents and has been credited with approximately 110 inventions. Her inventions include a vacuum ice cream freezer, a number of children's toys, and improvements to typewriters and sewing machines.

Born: September 28, 1887; Raleigh, North Carolina
Died: February 1973; New York, New York
Also known as: Lady Edison
Primary fields: Business management; household products
Primary inventions: Typewriter devices; children's toys; household devices; parasol improvements; sewing machine improvements

Early Life

Beulah Louise Henry (BYEW-luh LEW-eez HEHN-ree) was a descendant of the Revolutionary War hero Patrick Henry. Her grandfather was William Woods Holden, the governor of North Carolina in the 1860's. She was born in Raleigh, North Carolina, to artistic parents. Her mother was an artist, her father was an art expert, and her brother was a songwriter. As a child, she sketched out her ideas for inventions and made models from household scraps such as tape, soap, hairpins, buttons, and rocks. She lived in Memphis, Tennessee, for part of her youth, and attended college in North Carolina, at Elizabeth College and Queens College in Charlotte. She apparently received a liberal arts education, as she later described herself as having had no technical training.

Henry had synesthesia, a condition in which one type of stimulation evokes the sensation of another. For example, the hearing of a sound produces the visualization of a color or a taste. She said that she had a complete picture of each of her inventions in her mind before she tried to construct it or to describe it to someone hired to construct the invention for her. She felt that her ability to create complex mechanical devices without any technical training was due to the same "inner vision" that allowed her to see color and shape for musical notes.

In 1919, Henry moved to New York City and lived there most of her adult life. She did not marry, and she lived in hotels or hotel apartments all her life. She kept her rooms fairly empty of furnishings in order to allow room for her many models.

LIFE'S WORK

Henry's first patent was issued on September 3, 1912, while she was living in Charlotte. It was for an ice cream freezer with a vacuum seal. She was issued two more patents in 1913, while still living in Charlotte. One was for a handbag with interchangeable covers, issued on May 27; the other, issued on November 18, was for a parasol with snap-on covers of various colors that allowed the appearance of the parasol to be altered to match one's outfit. The parasol invention was both a commercial and a financial success for Henry. She earned about $50,000 from the manufacturer, probably Thomas Woodley of Charlotte, who was assigned one-half of the patent (U.S. Patent number 1,079,240). By 1921, Henry had formed the Henry Umbrella and Parasol Company in New York City to manufacture and sell her popular umbrellas and parasols. Her U.S. Patent number 1,492,725, issued May 6, 1924, for improvements to the above parasol was assigned to the Henry Umbrella and Parasol Company. By 1924, she was also president of B. L. Henry Company, her second company.

For the remainder of the 1920's, Henry was awarded numerous patents. Four were awarded in the year 1927 alone. Some were for additional improvements to the parasol. The majority, however, were for toys and household items, a couple of dolls, a floating soap holder made of a sponge that opened up to hold the soap, a hair curler, and several inflatable toys. Some of these patents were assigned partly or wholly to another individual or to a company, presumably to manufacture the items.

Starting in the 1930's, Henry began receiving patents for business machines. She was issued numerous patents for improvements to or devices for use with typewriters. She also received a number of patents for improvements to sewing machines. She continued to receive patents for toys, games, and household items. Several of her patents related to typewriters were for methods of producing multiple copies without carbon paper. This was especially important during World War II, because carbon for carbon paper was in short supply. Other typewriter-related inventions were for improved aligning devices, reduction in typing noise, and a key for use with devices such as a typewriter. In addition to her typewriter en-

DUPLICATION DEVICES FOR TYPEWRITERS

Beulah Louise Henry received several patents for devices that made multiple copies with a typewriter without the use of carbon paper. Her first patent of this type was issued in 1932, and she received patents for improvements up until 1959. The 1932 patent was for a "Duplication Device for Typewriting Machines." The invention consisted of several devices to be attached to a standard typewriter, so that the typewriter would then have an additional ribbon and the means to insert three sheets of paper: The first sheet would be behind the first (original) ribbon, the second sheet would be between the two ribbons, and the third sheet would be behind the additional ribbon. When the typist hit a key, the letter image would be placed on the front of the first sheet by the original ribbon, on the back of the second sheet by the second ribbon, and on the front of the third sheet by the second ribbon. The second (middle) sheet was supposed to be of transparent material, so that the typing could be read through it, since the letters would be on the back of the sheet. If only two copies were required, then a protective strip was placed between the front sheet and the second ribbon, so that the second ribbon would not print on the back of the first sheet. All of this was accomplished through a rather complicated set of mechanisms attached to the typewriter, so that the two or three sheets could be inserted properly with respect to the ribbons, and so that all three sheets would advance together properly.

The second patent, also issued in 1932, but applied for nearly two years after the first, was for an improved mechanism allowing the second ribbon to be swung out of the way in order to type on only a single sheet. The next improvement in a 1936 patent was for a separate, self-contained attachment, which could be removed when not required. It also allowed for more than three copies to be made. A 1937 patent was for an improved attachment that made insertion and removal of the sheets of paper easier. It also allowed for easier inactivation of the system to type single sheets or envelopes. Patents in 1953, 1954, and 1959 were for additional refinements to the multicopy attachment. They made it simpler, easier to use, and capable of making better typed copies.

With the later advent of photocopiers, and now computers, word processors, and printers, the multicopy attachment seems quaint. However, it served a useful purpose when it was invented, especially during World War II, and for decades after.

hancements, Henry was issued several patents related to envelopes, including construction of envelopes and continuously attached envelopes to aid in addressing them. Her improvements to sewing machines included improved devices for stitching and making seams, and a patent for a method of producing a lockstitch with only one thread, eliminating the need for a bobbin.

Henry began inventing toys early in her career. Several of her inventions made toys seem more realistic, such as a doll whose eyes would close or change colors, dolls with limbs that were movable in a variety of ways, a toy cow that could be milked, toy animals that ate, and dolls that talked. Several of her patents were for inflatable toys and for devices and methods of inflating them.

By the 1930's, Henry's prolific inventiveness was recognized, and she was nicknamed "Lady Edison." In addition to her inventing, she had a wide range of interests, including writing, painting, and membership in the Audubon Society, the League for Animals, and the Museum of Natural History.

Henry was hired by a number of companies in the latter part of her career to develop products for them. She is believed to have had more than one hundred inventions over her lifetime. Her last patent was issued on February 24, 1970, for a method of envelope construction. She died in February, 1973, at the age of eighty-five.

IMPACT

Henry was a prolific inventor. She was busy creating new inventions for most of her adult life. Her first patent was granted when she was twenty-four years old, and she was awarded her last patent at age eighty-two. She was one of the first female inventors to make a comfortable living from her inventing. She manufactured and sold some of her inventions through her companies, and some were licensed to other people or companies to manufacture. She had an amazing breadth of inventions, including improvements to parasols, her first commercial success; a wide variety of children's toys and games; household products; and a number of improvements to machines, notably typewriters and sewing machines.

Henry's early invention of a parasol with snap-on covers became widely used. Parasols and umbrellas were popular at that time, and the ability to change the parasol color in accord with one's outfit was well liked. Her inventions that allowed multiple typewritten copies to be made without carbon paper were of significance, given the shortage of carbon during World War II.

—*Harlan H. Bengtson*

FURTHER READING

Camp, Carole Ann. *American Women Inventors*. Berkeley Heights, N.J.: Enslow, 2004. Includes a chapter on each of nine American female inventors. Eight pages are dedicated to Henry, with pictures of her and some of her inventions.

Farquhar, Michael. *A Treasury of Foolishly Forgotten Americans*. New York: Penguin Books, 2008. Contains a chapter on Henry, with emphasis on her creativity and her ability to invent complex mechanical devices without the benefit of any technical education.

Stanley, Autumn. *Mothers and Daughters of Invention: Notes for a Revised History of Technology*. Metuchen, N.J.: Scarecrow Press, 1993. Includes a section on Henry, with information on her early life and her inventions. Includes information from several magazine and newspaper articles from the 1920's and 1930's.

See also: Clarence Birdseye; William Seward Burroughs; Bette Nesmith Graham; Herman Hollerith; Christopher Latham Sholes.

JOSEPH HENRY

American physicist

Henry's experiments in electromagnetic induction helped pave the way for the subsequent revolution in electrical technology. He invented the first electric motor and provided the scientific underpinning for Samuel F. B. Morse's telegraph.

Born: December 17, 1797; Albany, New York
Died: May 13, 1878; Washington, D.C.
Primary fields: Acoustical engineering; communications; electronics and electrical engineering; physics
Primary inventions: Electric motor; electromagnetic telegraph

EARLY LIFE

Joseph Henry was born to William and Ann Alexander Henry in Albany, New York, in 1797. His father was an alcoholic who had difficulty earning a living, and Henry spent part of his childhood and adolescence with his stepgrandmother and an uncle in Galway, New York, a small farming community approximately thirty-six miles from Albany. It was in the Galway village school where he received his basic education. He returned to Albany in 1814 or 1815 to live with his now widowed mother, who was running a boarding house. In Albany, he had a failed apprenticeship with a silversmith but gained valuable skills that he later used in creating experimental apparatuses. He had some success as an amateur actor and contemplated a career on stage. However, his life turned completely around when he stumbled upon a book belonging to one of this mother's boarders: George Gregory's *Popular Lectures on Experimental Philosophy, Astronomy, and Chemistry* (1808). Henry always dated his interest in science to the reading of that book in about 1816.

Henry became a schoolteacher and from 1819 to 1822 attended the Albany Academy, the only formal education he had beyond the primary grades. Subsequently, he worked as a tutor and as a surveyor before returning to the Albany Academy in 1826 as professor of mathematics and natural philosophy (physics). He left Albany for a professorship at the College of New Jersey (now Princeton University) in 1832.

LIFE'S WORK

In 1820, the Danish physicist Hans Christian Ørsted discovered that an electric current produced what later became known as a magnetic field. Researchers throughout Europe began exploring the relationship between electricity and magnetism. One of the leaders in that exploration was Michael Faraday in Great Britain. Unknowingly paralleling Faraday's research was Henry. Henry began his research in electromagnetism around 1827 by modifying existing apparatuses, with the objective of enhancing the phenomena for pedagogical purposes. He wanted to create spectacular results for demonstration purposes in the classroom. His initial fame was based on his ability to make extremely powerful electromagnets. By 1830, his electromagnets were able to support more than thirty-five times their own weight, making them the most powerful in the world. With his apparatuses, he was soon making original discoveries, fitting his research around an extremely demanding teaching schedule of at least seven hours a day. Sorting out priorities between Henry and Faraday has always

Joseph Henry. (National Portrait Gallery, Smithsonian Institution) been a challenge, especially since Henry did not maintain a laboratory record until 1834, but historians now agree that Faraday first published on the induction of an electric current by a changing magnetic field (1831), while Henry was the first to announce the existence of self-induction, the creation of a current in a wire when a circuit is broken (1832).

Although he saw himself as a research scientist, Henry was very aware of the potential applications of his discoveries. Henry's 1831 electromagnetic machine, although just a scientific demonstration, was the first apparatus to produce continuous motion through electromagnetic attraction and repulsion. It had all the essential elements of a direct-current (DC) motor. Although it should be considered the first DC motor, it was not the first step toward a practical invention. As Henry himself argued, the economic reality of the relative cheapness of the fuel for steam engines versus that for electrical engines in the mid-nineteenth century reduced the latter to curiosities. Moreover, Henry's oscillating design was quickly overtaken technologically by rotating motors.

It was a different story for the electromagnetic telegraph. As early as 1831, Henry had constructed a machine that demonstrated that electromagnetism could be used to produce mechanical effects at a distance (the ringing of a bell). By the mid-1830's, he had invented a primitive relay for his machine, an essential element for a commercial telegraph. In all his subsequent clashes with Samuel F. B. Morse over the question of who invented the telegraph, Henry never claimed he invented a commercial telegraph. He also always acknowledged that Morse's version was the best of the era and demonstrated the most superior reduction of principles to practice. What he did maintain was that he was the first to demonstrate the basic principle for the telegraph: how mechanical effects at a distance could be produced by the application of electromagnetism. His discoveries were a necessary element in the process of the invention of the telegraph. Without them, the invention of the telegraph would have been delayed indefinitely.

THE ELECTROMAGNETIC TELEGRAPH

By the early nineteenth century, researchers were aware of the potential of electromagnetism for use in telecommunications. However, experiments by the Englishman Peter Barlow in 1824 had shown that it was impossible to deflect a needle after sending a current through only two hundred feet of wire, thus making any form of long-distance communication impossible.

Joseph Henry was able to overcome this limitation through three insights. The early form of the electromagnet, invented by William Sturgeon in the mid-1820's, consisted of loosely wrapped bare copper wire around thick iron wire bent into the shape of a horseshoe. Because the wire was not insulated, only a few feet of wire could be wrapped around the iron before short circuits would develop. Henry painstakingly insulated the wire with silk, enabling him to wrap many layers of copper wire on the iron, resulting in a much more powerful electromagnet. His next insight was to replace the long coil of insulated wire with a series of shorter coils. He found that connecting the coils in parallel (which he called a "quantity magnet") enabled great lifting power at a short distance, but connecting the coils in series (which he called an "intensity magnet") produced a small amount of power at a great distance. By 1831, using an intensity magnet, he was able to transmit a current through one and a half miles of wire. His last insight, in 1835, was the development of a relay, using an intensity magnet to control a much larger quantity magnet.

The two different forms of electromagnets and the relay were essential for development of the telegraph. Morse's repeater, which made it possible for signals to travel great distances, was built around a Henry intensity magnet. Morse's recording instrument was dependent upon a Henry quantity magnet. The intensity to quantity relay was adapted by Morse for connecting his local receiving circuit to a long-distance telegraph line. The significance of Henry's insights to Morse's invention are evident by comparing the Morse telegraph before and after Morse was aware of Henry's work. In 1836, the Morse telegraph was able to transmit a signal only forty feet. After incorporating Henry's first two insights, at the advice of his friend Leonard Gale, a chemistry professor, Morse was able to send messages through ten miles of wire.

Initially, Henry and Morse had a cordial relationship that went back to at least 1838. Henry provided encouragement and technical advice to Morse, while Morse reciprocated by lending Henry apparatuses for scientific experiments. The relationship started to deteriorate in the mid-1840's, first because Henry felt Morse was denying him proper credit, and second because Henry testified in patent lawsuits, especially in *Morse v. O'Reilly* (1849). In the lawsuits, Henry challenged Morse's efforts to gain patent rights for all forms of the electromagnetic telegraph.

As one of the best-known scientists in the United States, Henry was selected as the first secretary (director) of the Smithsonian Institution in

1846. He remained secretary until his death. He was also a founding member (1863) and president (1868 until his death) of the National Academy of Sciences. By the 1860's, his research interests had shifted from electromagnetism to applied acoustics, especially the transmission of foghorn signals, an outgrowth of his service on the United States Lighthouse Board. He did, however, provide advice and support to Alexander Graham Bell in 1875, at what Bell perceived to be a crucial moment in his efforts to develop the telephone.

By the time of his death, Henry was recognized as one of the country's leading contributors to science, technology, and public service. Analogies were often drawn between Henry and Benjamin Franklin. In 1893, the International Congress of Electricians honored the pioneers in electrical research by attaching their names to fundamental electrical units. Henry's name was attached to the unit of inductance. When, at the end of the nineteenth century, the Library of Congress decided to memorialize sixteen outstanding contributors to human civilization, Henry was selected to be one of the representatives of science, along with Sir Isaac Newton, joining other icons like William Shakespeare, Plato, and Michelangelo.

IMPACT

Henry's contribution to the most significant invention in communications history in the nineteenth century, the electromagnetic telegraph, is one of the clearest examples of basic scientific research leading to significant technological innovation. His work also serves as an example of the scientist offering up his discoveries so that others might exploit them for technological innovation and financial reward. Using his positions as secretary of the Smithsonian and president of the National Academy of Sciences, Henry, drawing upon his own experience with the telegraph, became the leading spokesperson for the argument that basic research was essential for technological innovation and economic progress. He claimed that most of the significant inventions of the nineteenth century were the result of the application of scientific principles. Because of their contributions, scientists who discovered the fundamental principles were just as worthy of appreciation as the inventors who reduced ideas to practice and created the machine. Basic research was essential to the well-being of American society, not a luxury, and, he argued, should receive public support.

Henry was the first American scientist to make the case that scientific insights led to inventions, a case that was remade by the industrial research laboratories of the early twentieth century and by weapons researchers after World War II.

—*Marc Rothenberg*

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See also: Alexander Graham Bell; Michael Faraday; Samuel F. B. Morse; William Sturgeon.

HERO OF ALEXANDRIA

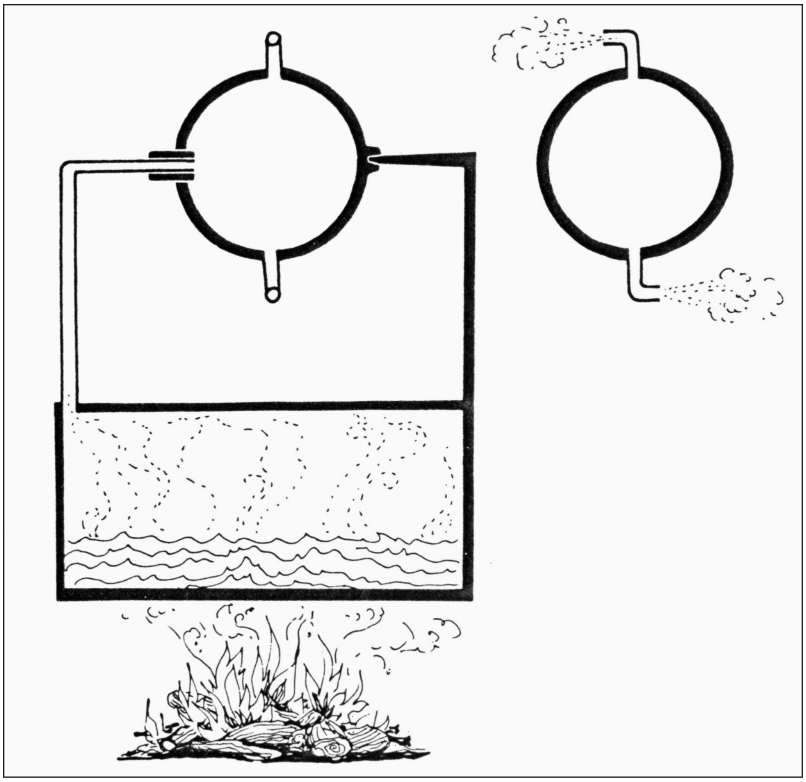
Greek mathematician and engineer

Hero invented, improved, or at least preserved the designs for a variety of devices, including a surveying instrument, a catapult, a coin-operated water dispenser, and automata. His most famous invention was the aeolipile, a forerunner of the steam engine.

Born: Before 62 C.E.; Alexandria, Egypt
Died: c. 100 C.E.; Alexandria, Egypt
Also known as: Heron of Alexandria
Primary fields: Mathematics; mechanical engineering; military technology and weaponry
Primary inventions: Aeolipile; coin-operated water dispenser

EARLY LIFE

Virtually no biographical information survives concerning Hero of Alexandria, but some details of his childhood can be reasonably surmised. Given his profession and judging from his voluminous writings, he probably came from at least a moderately wealthy family and received a first-class education. Alexandria, founded by Alexander the Great in 331 B.C.E., had become a thriving center for trade and scholarship under the Ptolemaic dynasty that ruled Egypt from 323 to 30 B.C.E. Though the Romans ruled Egypt in Hero's time, the city of Alexandria remained important both commercially and culturally. The young Hero would presumably have had access to the vast holdings of the Library of Alexandria and may well have attended the lectures of that institution's eminent scholars. In the form of its lighthouse, a hundred-meter-tall structure on the island of Pharos, Alexandria also offered a vivid daily reminder of the wonders that science and technology could achieve. Probably, but not certainly, of Greek descent, Hero was heir to a centuries-old tradition of intellectual curiosity and engineering innovation. In Alexandria, he would have been exposed to an incredibly diverse population of Greeks, Jews, native Egyptians, Romans, and other peoples from the Near East, Africa, and Europe. Perhaps only Rome itself could have offered a more fertile environment for a would-be inventor.



A representation of the aeolipile, an ancient steam engine. (The Granger Collection, New York)

LIFE'S WORK

What is known of Hero's work comes almost entirely from his writings. He wrote four works on aspects of mensuration, the science of measuring lengths, areas, and volumes. These works are his *Geometrica*, *Stereometrica*, *De mensuris*, and *Metrica*. Another work on geometry is his *Definitiones*. The works that discuss the construction of devices are the *Pneumatica*, about the use of compressed air, liquids, and steam; *De automatis*, describing the construction of two miniature automatic theaters; *Dioptra*, on a new surveying instrument; *Catoptrica*, which only survives in Latin translation, on mirrors; *Mechanica*, three books surviving only in Arabic translation, on the theory and practice of moving weights; and the *Belopoeica*, on catapults. Only fragments survive of his

Cheiroballistra, which describes another catapult-type weapon. Hero also wrote a volume on water clocks, a commentary on Euclid's *Elements*, and the *Baroulkos*, on a special lifting machine, but these works have not survived. Two later works, the *Geodaesia* and *Liber Geoponicus*, are collections of extracts from his writings.

In his writings, Hero describes a large number of useful, entertaining, and instructive devices, but it is seldom clear which devices he himself invented. In some cases, he merely describes earlier inventions, perhaps with minor improvements of his own. The *Belopoeica*, for example, only describes earlier types of catapults, not contemporary designs. Furthermore, it is sometimes uncertain whether a described device was ever actually built or could have really functioned. Some historians have gone so far as to deny that Hero was an inventor at all, asserting that he merely collected, organized, and published the designs of earlier innovators. However, his nickname, *mechanicus* (machine man), and the practical advice scattered throughout his writings suggest that he was more than just a compiler of information.

Hero was probably an adult by 62 C.E., since his *Dioptra* describes a lunar eclipse that occurred on March 13 of that year. It is unclear when Hero died, but a series of tantalizing references in late first and early second century sources may reflect his activities. Suetonius, the imperial biographer, mentions that the emperor Nero showed off a new kind of water organ in 68 C.E. This instrument, Paul Keyser has suggested, may have been the work of Hero, who describes a hydraulic organ in the *Pneumatica*. Pliny the Elder, who died in the eruption of Vesuvius in 79 C.E., reports in his encyclopedic *Naturalis Historia* (c. 77 C.E.) that a new type of wine press had recently been invented. This too may be the work of Hero, since he describes an innovative screw press design in his *Mechanica*. In his biography of Vespasian, Suetonius reports that the emperor rewarded an unnamed engineer for inventing a device designed to move heavy columns. If, as has been suggested, this is a reference to Hero, who shows considerable interest in such devices, then he was still active in the 70's. It is also likely that Hero invented the *cheiroballistra*, the small, torsion-powered arrow shooter he describes in the work of the same name. This weapon seems to appear on Trajan's Column and thus probably saw use in Rome's wars with Dacia in the first decade of the second century.

Hero invented (or at least recorded the designs for) dozens of devices. Among the most important are the aeolipile, the dioptra, various automata, automatic doors, a coin-operated water fountain, a variety of trick containers for water and wine, a wind-powered organ, a machine

THE AEOLIPILE

Among the many inventions of Hero of Alexandria, none have exerted the same amount of fascination as his so-called aeolipile, or "wind ball," which some historians have described as the first steam engine and earliest jet turbine. Hero briefly explains the construction of this device in his *Pneumatica*. The device is quite simple, consisting of two metal chambers, three tubes, and a rod. The first chamber is a hollow hemisphere or covered cauldron and is meant to be filled with water. When this vessel is heated, the water gradually turns to steam and escapes through a tube or pipe leading to a hollow sphere. This pipe and a rod also attached to the cauldron hold up the sphere and are connected to it in such a way that the sphere can pivot around the axis they form. The steam, after entering the sphere, is allowed to escape through two additional L-shaped tubes set opposite one another along its circumference equidistant from the "poles" formed by the rod and tube connecting the sphere and the hemisphere. The exhaust ends of the L-shaped pipes point in opposite directions so that the force of the escaping steam causes the sphere to rotate around its axis. The classicist J. G. Landels, an expert in ancient science and engineering, reported that his own model of the aeolipile reached speeds of 1,500 revolutions per minute.

There continues to be some dispute over the precise significance of Hero's steam engine. Some scholars have essentially dismissed the device as no more than a toy without any practical application. Others have suggested that Hero intended the aeolipile not to do work but to demonstrate fundamental physical principles. This position seems reasonable given that the introduction to the *Pneumatica* explores the nature of air, water, and vacuum in general. Nevertheless, it is remarkable that this device, mentioned in no other ancient text, receives no special comment or explanation from Hero amid the other, more banal inventions described in this work. Another recurring debate concerning the aeolipile asks why Hero or some other ancient inventor did not adapt it for useful work, precipitating an ancient industrial revolution. The answer seems to be that the lack of proper fuel, construction materials, and tools impeded further development. Some have also suggested that the slave-based Roman economy did not place a sufficient premium on labor-saving machines to promote further development of the device.

for cutting female screws, a fire pump, self-regulating oil lamps, and the syringe. The dioptra was a forerunner of the theodolite, used by surveyors to measure horizontal and vertical angles. Hero's dioptra lacked the theodolite's telescope but could be used to excavate a straight tunnel through a hill or mountain from both ends simultaneously or estimate the distance to an inaccessible or dangerous spot such as an enemy's fortifications. The automata Hero describes include a miniature theater that would produce a multiact Greek tragedy complete with sound effects. His automatic doors opened a temple when a worshiper lit a fire on an external altar. The doors would close again when the fire was extinguished. Hero's coin-operated fountain worked in much the same way as the tank of a modern flush toilet. A coin fell through a slot onto a plate attached to a lever. The coin's weight depressed its end of the lever, lifting a plug attached to the other end and allowing water to flow out. Once the coin slipped off the plate, the plug returned to its initial position, stopping the flow of water. The *Pneumatica* describes a number of trick vessels in which one could pour wine and water and then, depending on which air holes were open or blocked, pour out either wine, water, or a mixture. Hero's windmill-powered organ is the only known application of wind power (aside from sailing) to survive from classical antiquity.

IMPACT

The mere fact that Hero's writings survived him suggests that later Greek and Roman thinkers considered his work to be important. Writing materials and scribes were expensive, so the preservation of Hero's work constituted a significant investment. A lack of sources makes it difficult to assess Hero's impact in antiquity, but Pappus of Alexandria, an early fourth century scholar, suggests that Hero had many followers. To this day, Hero's books remain a vital source for the study of ancient mathematics, engineering, surveying, and natural philosophy because so few other works on these subjects survive.

The impact of Hero's ideas and inventions in later periods is somewhat easier to gauge and seems to have been considerable. Scholars in the Islamic world preserved some of his writings, demonstrating their continued importance. Hero's wind-powered organ may have inspired Islamic engineers to develop the windmill. Many in both the Islamic world and the Byzantine Empire were inspired, directly or indirectly, by the wonderful automata described in the *Pneumatica* and sought to emulate them. Hero was not forgotten in medieval Europe, but interest in him increased dramatically in the Renaissance. In Italy and elsewhere, demand for automata grew. Humanist scholars also took an interest in Hero, particularly his ideas about the vacuum, and translated the *Pneumatica* into Latin, Italian, and German. Leonardo da Vinci, Francis Bacon, and Robert Boyle were all familiar with his writings. Hero's aeolipile even contributed to early efforts to design functional steam engines.

—David B. Hollander

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See also: Archimedes; Giovanni Branca; Ctesibius of Alexandria; Leonardo da Vinci.

HEINRICH HERTZ

German physicist and electronic engineer

Hertz invented the first radio transmitter and receiver and used them to discover radio waves and confirm that they are electromagnetic waves that travel at the speed of light. He also discovered the photoelectric effect, in which light produces electricity.

Born: February 22, 1857; Hamburg (now in Germany)
Died: January 1, 1894; Bonn, Germany
Also known as: Heinrich Rudolf Hertz (full name)
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Radio transmitter and receiver

EARLY LIFE

Heinrich Rudolf Hertz (HIN-rihk REW-dahlf HURTZ) was born on February 22, 1857, in Hamburg (now in Germany). His father, Gustav Ferdinand Hertz, was Jewish but converted to Christianity and raised his family as Lutherans. He was well known as a lawyer and became a senator in 1887. Heinrich's mother, Anna Elisabeth, was the daughter of a Frankfurt physician, Dr. Pfefferkorn. When Heinrich graduated from the Johanneum Gymnasium (secondary school) in 1875, he was first in his class, having studied Greek, Arabic, and Sanskrit. He was the eldest of four sons and one daughter.

After working for an engineering company in Frankfurt for a year, Hertz left in April of 1876 to enroll in engineering at the Dresden Technical Institute, but he left in September to fulfill a year of mandatory military service with the First Railway Guards Regiment in Berlin. He soon decided that his real interest was in science, and in 1877 he enrolled in physics at the University of Munich. A year later, he transferred to the prestigious Physical Institute at the University of Berlin, where he studied under Gustav Kirchhoff and Hermann von Helmholtz, two of the foremost physicists of the day.

Under the guidance of Helmholtz, Hertz won first prize for his electrical research entitled "Experiments to Determine an Upper Limit to the Kinetic Energy of an Electric Current." In 1880, he obtained his Ph.D. with a thesis on electromagnetic induction in rotating spheres, graduating magna cum laude. He then continued in Berlin for three years as the assistant of Helmholtz, publishing fifteen papers on both electrical and mechanical topics, which included early studies of contact forces associated with two objects under loading.

LIFE'S WORK

Heinrich Hertz was an unusual physicist in that he was skilled in both experimental and theoretical physics, both of which he employed during his short career. His first university appointment was in 1883 as a lecturer at the University of Kiel. He remained in contact with Helm-

Heinrich Hertz. (Library of Congress)

The Radio Transmitter and Receiver

The inventions by Heinrich Hertz of the first wireless radio transmitter and receiver were the result of a process of trial and error, followed by systematic experiments to confirm his results. The primary of his induction coil was fitted with an electromechanical vibrator to interrupt the current and produce a pulsed high voltage across the secondary. His antenna oscillator was a dipole consisting of two zinc-covered spheres acting as charge-storing capacitors. Each sphere was connected with a variable length of wire to the terminals of a spark micrometer, which in turn were connected to the secondary of the induction coil. The separation of the spheres could be varied up to 3 meters to support half-wavelength oscillations at resonance, thus producing up to 6-meter wavelengths that were short enough for convenient indoor measurements. The high-voltage pulses charged the spheres until a spark discharged them. About five or six discharges in each pulse produced oscillating currents in the antenna up to 50 megahertz.

At first, Hertz used a loop of wire connected to another spark micrometer as a way of measuring the resonant frequency of the antenna oscillator. When the loop radius was adjusted to resonance, it sparked at the same time as the oscillator. He could then determine their common frequency by calculating the loop frequency. When he found that he could obtain synchronous sparks several meters away, he realized that his antenna oscillator was a wireless transmitter and that he was detecting electromagnetic waves from the transmitter with his variable loop, which was the first radio receiver. He was even able to detect these sparks in an adjacent hallway as the radio waves passed through the walls.

After these inventions, he began a series of experiments in the fall of 1887 to demonstrate that the radiation from his transmitting oscillator corresponded to James Clerk Maxwell's prediction of electromagnetic waves traveling at the finite speed of light. He set up his induction coils and oscillator at one end of a 15-meter lecture hall and covered the opposite wall with a sheet of zinc to reflect the radiation. When he moved his receiving loop and spark gap away from the oscillator, he observed a periodic variation in the strength of sparks, with nodes about 4.8 meters apart, corresponding to a 9.6-meter wavelength in the standing waves produced by the transmitted waves and their reflection. This value was distorted to some extent by the small size of the room relative to the wavelength.

With the radius of the loop at about 35 centimeters, Hertz calculated a resonant frequency of 35.7 million vibrations per second (megahertz), giving a wave speed (frequency × wavelength) of 3.4 × 10 meters per second, about 13 percent more than the measured speed of light. Later corrections by Henri Poincaré showed that the frequency was 50 megahertz and the wavelength was 6 meters, giving a speed of 3 × 108 meters per second, matching the speed of light. These experiments were completed in March of 1888 and published in his paper "On Electromagnetic Waves in Air and Their Reflection," initiating a new era of wireless communication.

holtz, who was one of the first European scientists to seriously study James Clerk Maxwell's 1865 electromagnetic theory and tried to derive Maxwell's field equations using action-at-a-distance assumptions. In Hertz's first paper on electromagnetic theory in 1884, he ignored such assumptions and eliminated the mechanical models that Maxwell had used to justify the theory. He concluded with the modern view that the theory is in essence the equations of Maxwell regardless of how they are derived. In 1872, Maxwell had predicted that oscillating charges should produce electromagnetic waves that travel at the speed of light, but Hertz was unable to test Maxwell's prediction due to the lack of laboratory equipment at Kiel.

In 1885, Hertz accepted a position at the Technische Hochschule in Karlsruhe, which had a well-equipped laboratory. There he met Elizabeth Doll, a professor's daughter, and married her in 1886. They had two daughters, Johanna, born in 1887, and Mathilde, born in 1891. Shortly after arriving in Karlsruhe, Hertz found some large induction coils that could produce a pulsed high voltage and a pair of spark micrometers with brass knobs forming an adjustable spark gap, which he hoped could be used to transmit electromagnetic waves as predicted by Maxwell. With a battery and an interrupter attached to the primary coil, he could obtain a pulsed high voltage across a secondary coil. He then invented a high-frequency oscillating antenna by forming a dipole with two metal spheres about three meters apart connected to the terminals of the secondary coil. He connected one of the spark micrometers between the two terminals, where the wires from the spheres were connected to act as a high-frequency switch.

To measure the frequency in this antenna oscillator, he used a loop of wire with an adjustable length connected to the other spark micrometer. Holding the loop close to the antenna oscillator, Hertz was able to adjust its radius until sparks would form in the gap when the resonant frequency of the loop matched that of the oscillator. He could then calculate the frequency of the loop to determine the corresponding frequency of the oscillator. He published his experiments with this oscillating antenna in 1887 in a paper entitled "On Very Rapid Electric Oscillations."

In the course of these measurements, he noticed that sparks would appear in the loop even when it was moved a few meters away from the antenna, and he realized that he was detecting electromagnetic waves from the antenna. This was in effect the invention of wireless radio, with his antenna oscillator as the first radio transmitter and his loop as the first radio receiver. He then did a series of experiments to show that these were electromagnetic waves, including measurements of frequency and wavelength, the product of which gave the speed of light as predicted by Maxwell. He also showed that these waves were like light in their reflection, refraction, polarization, and diffraction.

In the course of his experiments with what are now called radio waves, Hertz made the unexpected discovery of the photoelectric effect, in which light produces electricity. He first observed that the induced spark in his receiving loop was strengthened, as measured by the spark micrometer, when the light of the larger spark in the oscillator illuminated the induced spark in the loop. He also showed that the spark was enhanced even more when illuminated by ultraviolet light. These results were published in 1887 in his article "On an Effect of Ultra-Violet Light upon the Electric Discharge." After his discovery of radio waves was confirmed by others, Hertz received many invitations from universities and finally moved to the University of Bonn in 1889, where he began a study of cathode rays and wrote a book on mechanics. At Bonn, he had several operations on his head for malignant bones, and on January 1, 1894, he died of blood poisoning at the age of thirty-six.

IMPACT

The main impact of Hertz's work came from his invention of radio and the associated discoveries of radio waves and the photoelectric effect. Although Hertz was primarily interested in clarifying electromagnetic theory, and never mentioned applications of his work, radio opened up new communication technologies and new extensions of the electromagnetic spectrum. One of the earliest applications of radio waves was by the Italian engineer Guglielmo Marconi after reading papers by Hertz in 1894. Marconi replaced the spark gap between the ends of the dipole antenna with a tube of metal filings called a coherer, which greatly increased the current in the antenna. By 1896, he had succeeded in sending coded messages far enough to warrant a patent, and by 1898 he had transmitted signals from Ireland to Scotland. On December 12, 1901, he sent wireless signals across the Atlantic from England to Newfoundland, using balloons to lift his antennas as high as possible.

The work of Hertz clarified and confirmed electromagnetic theory, leading to both relativity and quantum theory. It opened up a new understanding of the entire spectrum of electromagnetic waves from radio to X rays, all of which travel at the speed of light but differ in frequencies and wavelengths. The absolute value of the speed of light was the basis for Albert Einstein's special theory of relativity, proposed in 1905. The photoelectric effect was studied systematically after Hertz died by his assistant Philipp Lenard, who showed in 1902 that the energy of photoelectrons increases with the frequency of the incident light that produces them. This discovery was used by Einstein in 1905 to confirm and generalize quantum theory, and it is the basis for such devices as digital cameras, in which light signals are changed into electric currents.

—Joseph L. Spradley

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See also: Thomas Alva Edison; Albert Einstein; Michael Faraday; Oliver Heaviside; Hermann von Helmholtz; Joseph Henry; Robert Jarvik; Gottfried Wilhelm Leibniz; Guglielmo Marconi; Nikola Tesla.

PETER COOPER HEWITT

American electrical engineer

Hewitt's invention of the bright and efficient mercury-vapor lamp provided an important component of industrial lighting through the first half of the twentieth century. With little loss of heat energy, the Cooper Hewitt lamp demonstrated the effectiveness of conveying electrical charges through gases and was a precursor to the fluorescent light.

Born: May 5, 1861; New York, New York
Died: August 25, 1921; Paris, France
Primary fields: Aeronautics and aerospace technology; electronics and electrical engineering
Primary inventions: Mercury-vapor lamp; mercury-arc rectifier

EARLY LIFE

Peter Cooper Hewitt was born in New York City in 1861. His father was Abram Hewitt, a successful manufacturer, businessman, and from 1886 to 1888, mayor of New York City. His mother was Sarah Amelia Cooper Hewitt. Sarah was the daughter of one of New York City's most famous residents, Peter Cooper, a brilliant inventor in his own right, wealthy industrialist, and philanthropic founder of Cooper Union. Grandfather Cooper taught mechanical skills to Peter and his other grandson Edward. He had a workshop with a lathe, forge, tools, and a steam engine built for the boys, and he hired a mechanic to teach them how to use the implements. When Alexander Graham Bell visited Cooper to explain the workings of his new telephone, Cooper called in Peter and Edward to see the demonstration. The boys returned to their workshop and built a makeshift phone. Strung across the street to a friend's house, it may have been the first house-to-house phone in New York City.

Peter Cooper Hewitt was educated by private tutors, at the Stevens Institute of Technology in Hoboken, New Jersey, and at Columbia University, where he specialized in economics, physics, and chemistry. Recognizing Hewitt's interest and talent for mechanical invention, his grandfather made available to him an old greenhouse as a laboratory for experimentation. Young Hewitt improved machinery in his grandfather's glue factory and invented new models of centrifugal machines and evaporators for use in New York's ubiquitous breweries.

On April 27, 1887, Hewitt married Lucy Bond Work. Given the prominence of the two families, the wedding was considered the social affair of the season, catered by Delmonico's restaurant. A few years later, Hewitt was involved in a well-publicized controversy with the New York police in May, 1890. Hewitt was leaving Madison Square Theatre when he argued with a hansom cab driver. The driver lashed Hewitt with his whip, and Hewitt smashed his cane on the driver's head. A police officer, not knowing Hewitt's prominence, arrested and manhandled him.

LIFE'S WORK

Hewitt received three important legacies from his distinguished family. First, he inherited a genius for mechanical invention from his illustrious grandfather and namesake, Peter Cooper. Second, like his grandfather, he followed unorthodox and intuitive methods in developing new technology, relying on experimentation and trial and error rather than theoretical science. Third, he inherited from his father a fortune that allowed him to pursue his scientific interests unhindered.

Working in his laboratory, which eventually occupied five floors in the Madison Square Garden Tower in New York City, Hewitt produced a steady stream of inventions around the turn of the century. Hewitt discovered that if he electrified a quantity of mercury in a vacuum tube, a vapor was formed that could conduct electric currents and produce other extraordinary phenomena. This discovery would become the basis of his life work. In 1898, he produced his most significant invention, the mercury-vapor lamp, also known as the Cooper Hewitt lamp (patented in 1901). It consisted of a quartz or glass tube containing mercury, mercury vapor, and wires connected to an electric current. The tube was sealed vacuum-tight. The contents of the tube conducted electricity to and from the vapor carrying the current. Designed to produce more light and less heat than incandescent lights, Hewitt's mercury-based lamp represented a pioneering effort in employing gases to conduct electrical charges.

Peter Cooper Hewitt. (Library of Congress)

Based on his research for the mercury-vapor lamp, Hewitt made other inventions that advanced knowledge of the interaction of electrical charges and gases. Because the light emitted from his lamp was a strange bluish-green color, without red radiation, Hewitt designed a transformer that restored parts of the color spectrum that had been eliminated. He invented the mercury-arc rectifier (also known as a static converter) in 1902. This invention converted alternating electric current into direct current, thus allowing the use of apparatuses designed to work on one kind of current to work on the other kind of current. Hewitt would receive the prestigious Elliott Cresson Medal in 1914 from the Franklin Institute for this important invention. A related invention was Hewitt's electrical interrupter, which could turn off high-tension currents and could make or break a circuit. Hewitt's final invention that grew out of his researches into charged vapors was a wireless telegraph receiver. This invention detected wireless telegraph signals by means of a mercury-vapor tube with an electrode. Hewitt's telegraph receiver increased sensitivity for detecting signals without increasing the possibility of burnout. Engineer, entrepreneur, and industrialist George Westinghouse purchased patent rights to the mercury-vapor lamp from Hewitt. In 1902, Westinghouse provided the capital to launch the Cooper Hewitt Electric Company to develop, manufacture, and market Hewitt's gas-based electrical lamps. Hewitt's productivity in his electrical researches was made possible by his disciplined work habits. He devoted mornings to his business interests and his afternoons and evenings to his scientific experiments. For recreation, he attended the leading social and athletic clubs in New York.

In the beginning of the twentieth century, Hewitt turned his attention to the engines and modes of transportation characteristic of the new age. As to the automobile, he improved a means of regulating engine speed and assisted his brother, Edward Hewitt, in the manufacture of the Hewitt automobile. As to watercraft, in 1907 he developed a motorboat that employed an eight-cylinder engine to lift the hull on four wing-shaped hydrofoils. With the hull freed from the friction of the water, the boat was able to achieve higher speeds. This motorboat was a precursor of high-speed hydroplanes. As to aircraft, Hewitt made several innovations. He wrote popular articles in 1908 in which he daringly predicted that air travel would one day be inexpensive and widely available. He received a patent in 1915 for an aerostat (balloon) envelope and supporting truss. In 1920, he acquired three patents for a prototype helicopter. Columbia University professor Francis Crocker assisted Hewitt in constructing a model of a machine that could elevate vertically.

Hewitt worked on behalf of American inventors as a member of the board of governors of the Inventors' Guild and as a member of the Naval Advisory Board. For use by the Navy, he designed an aerial torpedo. Columbia University awarded Hewitt an honorary doctorate in 1903, and Rutgers College did likewise in 1916. Hewitt's divorce from his first wife, Lucy, in December, 1918, made a minor sensation in the New York City papers, as they had been a prominent society couple in New York, lavishly entertaining in the Cooper Hewitt mansion on 11 Lexington Avenue in the Gramercy Park neighborhood. Hewitt married Maryon J. Bruguiere on December 21, 1918, only a few days after obtaining the divorce. (It was later revealed that Hewitt's only child, Ann, was born to Bruguiere in Paris in 1914; Ann would be involved in a notorious court case in 1936 over Hewitt's million-dollar estate.) Hewitt died in Paris in 1921.

THE COOPER HEWITT MERCURY-VAPOR LAMP

Peter Cooper Hewitt's low-pressure mercury-vapor lamp was designed to address one of the perennial problems of the electric light—the loss of energy through heat. In the first incandescent electric lamps, only about 3 percent of the energy was converted into illumination. The remaining 97 percent was lost, mostly as heat. In the 1890's, Hewitt began experimenting with electrical discharges to solve this problem. Cooper's lamp would demonstrate the ability of gas to conduct an electrical charge. Hewitt built on the work of German scientists Julius Plücher and Heinrich Geissler, who had succeeded in passing electric currents through glass tubes containing tiny amounts of gas. Hewitt experimented with passing electric currents through mercury-filled tubes. In 1898, he succeeded in developing a commercial lamp consisting of an elongated quartz tube containing mercury gas. He patented the lamp in 1901 (U.S. Patent number 889,692).

The lamp was activated by tipping so that the mercury would run from one electrode to the other. The lamp was made of hard borosilicate glass, and the mercury was sealed under high vacuum. With a current of 3.5 amperes, the lamp's total light output was about 6,900 lumens. An electric current from an anode electrode of iron or tungsten to a cathode electrode of mercury vaporized the mercury, emitting an intense but cool light. Because the emitted light was an unattractive bluish-green color, the lamp was not suited for domestic use. However, its greater efficiency in producing light, as much as eight times that of incandescent lamps, made it ideal for industrial purposes, such as in factory lighting, street lamps, and photography studios. The lamp was also helpful in a variety of chemical, therapeutical, and sterilizing operations.

The Cooper Hewitt Electric Company was only moderately successful, however, because of the almost pound of mercury required by each lamp. In addition, many improvements were being made to competing incandescent lamps, such as the use of more efficient tungsten filament. In 1919, the General Electric Company acquired the Cooper Hewitt Electric Company. In 1933, General Electric's Vapor Lamp Department began marketing a much improved high-pressure mercury-vapor lamp that had been developed in Europe and that used only a fraction of the mercury required by the older Cooper Hewitt lamps. General Electric ceased production of the Cooper Hewitt lamp in 1965. Although the lamp itself fell into disuse, it is of historical importance. As the Cooper Hewitt lamp pioneered the use of mercury vapor to create luminescence, it can be seen as the prototype of the modern fluorescent lamp.

IMPACT

Hewitt followed in the footsteps of his famous grandfather and namesake, Peter Cooper, in ingeniously inventing and improving a wide range of devices practical in the commercial world. His four most important inventions—the mercury-vapor lamp, the mercury-arc rectifier, an electrical interrupter, and a wireless receiver—were the result of his study of electric currents in a vacuum tube containing mercury. These devices not only were important industrial instruments but also demonstrated pioneering technological principles. The mercury-vapor lamp showed the effectiveness of employing the motion of electricity through rarefied gases and vapors. Hewitt's success with the lamp helped spur interest in this field of electrical science. His mercury-vapor lamp was also the forerunner of the fluorescent lamp. Hewitt's experiments demonstrated the importance of the rectifying characteristic of electrodes in rarefied gases and led to the invention of his wireless telegraph receiver. His rectifier allowed for direct current to be economically converted from alternating current at its final destination. Acting as a simple transformer, this rectifier was able to replace expensive and heavy rotary converters. Hewitt's research into the nature of moving electricity in a vacuum tube contributed to the development of the vacuum-tube amplifier for radio telephony. Hewitt was also a pioneer in the development of hydroairplanes, high-speed motorboats, and the helicopter.

Coming from a family of inventors and possessed of an independent fortune, Hewitt, nicknamed "the millionaire inventor," was able to fund his own experiments, unaffiliated with any institution. His curiosity and ingenuity produced a variety of inventions, improved by his unorthodox methods and imaginative techniques. As such, Hewitt represents a tradition of independent invention that would become increasingly rare in the twentieth century.

—*Howard Bromberg*

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See also: Peter Cooper; Thomas Alva Edison; Elmer Ambrose Sperry; George Westinghouse.

WILLIAM REDINGTON HEWLETT

American engineer

Hewlett cofounded the Hewlett-Packard Company, a manufacturer of computer hardware and software and one of Silicon Valley's first start-up companies. Hewlett's audio oscillator was the company's first financially successful product.

Born: May 20, 1913; Ann Arbor, Michigan
Died: January 12, 2001; Palo Alto, California
Primary fields: Computer science; electronics and electrical engineering
Primary invention: Audio oscillator

EARLY LIFE

William Redington Hewlett was born in Ann Arbor, Michigan, on May 20, 1913. His father was an influential physician and a faculty member at the University of Michigan. When Hewlett was three years old, his father transferred to Stanford University and the family moved to the San Francisco Bay Area. Hewlett's father died suddenly when Hewlett was twelve, but the family survived the hardship and the boy continued to benefit from the dynamic cultural, scientific, and literary surroundings in the growing San Francisco region.

Hewlett attended Lowell High School in San Francisco, but he did not do well there because he suffered from dyslexia—a language-based learning disorder very poorly understood or accommodated at the time. The dyslexic person has difficulty reading well, sometimes reversing letters as he or she reads or writes. As inconvenient as it is for anyone to master academic subjects with this condition, a number of dyslexics are excellent visual thinkers. Many scientists and inventors have discovered that they can clearly imagine new machines in their minds. This disability can be a surprising asset to the mechanically inclined if their true ability can be recognized early enough. Hewlett was fortunate to have his knack for understanding how things worked brought to the attention of his high school principal, who saw past his poor grades, urged Hewlett to enroll at Stanford, and encouraged the university to accept him.

LIFE'S WORK

Hewlett's life work began earlier than most with his entrance in college in 1930. Hewlett was again blessed to have found a mentor in Professor Frederick Terman, one of Stanford's most famous professors, who also had a large role in the development of the computer industry in Silicon Valley. Hewlett also met and became a close personal friend with David Packard—a vital friendship that developed into a synergistic, inventive collaboration and business partnership as they founded the Hewlett-Packard Company. When Hewlett graduated from Stanford in 1934, he went to the Massachusetts Institute of Technology (MIT), where he earned his master's degree in engineering in 1936.

That year, Hewlett returned to California to continue his graduate studies in engineering at Stanford, receiving a master of engineering degree in 1939. Professor Terman again significantly shaped the lives of both Hewlett and Packard by encouraging them to form their own company soon after they graduated. With little founding investment capital, the original headquarters of the Hewlett-Packard Company was in a garage. They also did not have money for a marketing survey to select a proper name for the company, so they decided to name it after themselves and flipped a coin to decide which of their last names would come first. The year 1939 was also important in that Hewlett married Flora Lamson. They eventually raised five children together.

In 1940, Hewlett invented the audio oscillator in his lab at Stanford, and it became the company's first commercial success. Eight of the machines—priced at $71.50 apiece—were sold to Walt Disney's new company to be used to create the 1940 hit film *Fantasia*. Far from being a stage prop for an animated movie, the audio oscillator was a valuable technical tool for physicians, clinical technicians, engineers, geologists, oil explorers, miners, the U.S. military, and others.

Hewlett-Packard founders William Redington Hewlett, left, and David Packard work on electronic counters at their factory. (Time & Life Pictures/Getty Images)

While Hewlett worked virtually his entire life at Hewlett-Packard, he did spend four years as an officer in the Army during World War II. Even then, his work was not far removed from technical engineering work. He first served on the staff of the Army's chief signal officer but was soon elevated to the head of the New Development Division of the War Department's Special Staff. In 1945-1946, he was on the special U.S. team that evaluated Japanese industry in the immediate aftermath of the war.

In 1947, Hewlett returned from the military to become the company's vice president, while Packard served as president. Hewlett moved up to executive vice president in 1957 (the year the company went public) and president in 1964, when Packard became chairman. Hewlett became the chief executive officer (CEO) when Packard served as the deputy secretary of defense in Richard M. Nixon's administration. Whatever the job titles, it is generally acknowledged that Hewlett and Packard worked well together.

Hewlett-Packard did not enter the minicomputer market until 1966. Nonetheless, its first computer, the 2116A, was truly innovative. Nearly all early computers were heat-generating, heat-sensitive, delicate machines requiring large and expensive air conditioning units for the rooms in which they were located. Most also had to be installed on spring-loaded floors to prevent damage from shaking. Hewlett-Packard planned its first computer as an instrumentation computer. As such, the company decided it needed to be as rugged and reliable as the other instruments with which it was to work. As a consequence, Hewlett-Packard is credited with inventing the first "go-anywhere, do-anything" computer. While Hewlett-Packard is most prominently associated with computers, it is important to remember that the company also provided a wide range of technical equipment for manufacturing, testing, measuring, copying, scanning, printing, and calculating.

In 1966, Hewlett and his wife founded the William and Flora Hewlett Foundation, which supports a number of educational and cultural institutions. Flora Hewlett died in 1977, and William married Rosemary Bradford the following year. He died in 2001 at the age of eighty-seven.

IMPACT

Hewlett had a significant impact not only on the invention and development of computers and their auxiliary products but also on the industry in general. He and Packard are credited with creating a productive corporate work environment in which employees were highly regarded. So famous is this aspect of the Hewlett-Packard corporate ethos that it has earned the sobriquet "The HP Way." Hewlett-Packard was one of Silicon Valley's first start-up companies and one of its most successful. At the time of Hewlett's death, Hewlett-Packard was the thirteenth largest corporation in the United States, with about ninety thousand employees in 120 countries around the globe and annual sales of nearly $50 billion.

—*Richard L. Wilson*

THE AUDIO OSCILLATOR

William Redington Hewlett created the prototype for the audio oscillator as a part of his engineering thesis work at Stanford University in 1938. After graduation in 1939, he refined the device, and it became Hewlett-Packard's first commercially successful invention, the Model 200A. An audio oscillator creates one frequency (pure tone) at a time. As such, it can be used to create or maintain telephones, stereo recording equipment, radios, or other audio equipment.

Hewlett realized that there was a need for a device that combined the stability of a coil-condenser oscillator with the more flexible operation of a beat-frequency type of oscillator. Such a machine would also need to be adjustable, simple in construction, light, and portable. The Model 200A was a completely new kind of oscillator in which the frequency-determinator was a resistance-capacity network. This invention achieved superior performance at a low cost by using a small light bulb in the oscillator circuit to provide negative feedback. The light bulb works with partial current. As the oscillator's signal strength becomes greater or lesser, the light bulb increases its consumption of current to a stronger or weaker degree to eliminate unwanted variations. Thus, the oscillator provides a steady output over its desired operational range.

One of Hewlett-Packard's first customers was the Walt Disney Company, which ordered eight of the machines to test sound equipment for its new Fantasound sound system for the full-length animated film *Fantasia* (1940).

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See also: Walt Disney; Ken Olsen.

JAMES HILLIER

Canadian American physicist

Hillier was a prolific research physicist who, with Albert Prebus, designed and built the first successful high-resolution electron microscope in the Western Hemisphere in 1938.

Born: August 22, 1915; Brantford, Ontario, Canada
Died: January 15, 2007; Princeton, New Jersey
Primary fields: Electronics and electrical engineering; medicine and medical technology; physics
Primary invention: Electron microscope

EARLY LIFE

James Hillier was born in Brantford, Ontario, Canada, to James and Ethel (Cooke) Hillier. His father was a mechanical engineer, a fact that may have played a role in the boy's interest in building and designing scientific equipment. As a child, he was interested in ham radio and spotting aircraft in the area. His father bought him a telescope so he could read the numbers on the planes as they flew overhead, and Hillier eventually converted the eyepiece into his first microscope. He expressed an early interest in art, music, and photography and also participated in swimming and boating. He attended high school at the Brantford Collegiate Institute, then completed his education at the University of Toronto, where he received three successive degrees in physics: a B.A. in 1937, an M.A. in 1938, and finally a Ph.D. in 1941.

James Hillier, standing, works with Vladimir Zworykin on an electron microscope, which Hillier invented with Albert Prebus in 1938. (Getty Images)

In 1938, then graduate student Hillier and fellow student Albert Prebus developed a prototype of the electron microscope by adapting the existing work of German scientists. This prototype later became the first commercially successful high-resolution electron microscope. In 1939, Hillier was made a research assistant at the Banting Institute of the University of Toronto Medical School in order to continue the development of the electron microscope. Hillier moved to the United States in 1940, where he was employed by the Radio Corporation of America (RCA) at its electronics research laboratory in Camden, New Jersey. In 1945, he became a U.S. citizen.

Hillier was married on October 24, 1936, to Florence Marjory Bell, daughter of William Wynship Bell in Erindale, Ontario. The couple had two sons: James Robert Hillier and William Wynship Hillier.

LIFE'S WORK

During the 1930's, medical science was struggling to understand the role of microbes in human and animal health. Many disease-causing organisms such as bacteria and viruses were too small to be viewed with traditional microscopes, as were human and animal cells. Medical advances were largely dependent on the sophistication of existing and emerging technology. After developing the electron microscope, Hillier took it to RCA, where he continued to make improvements to the device. Within a short time, he had the electron microscope operating near its theoretical limit of efficiency.

In 1940, Hillier designed the first commercial electron microscope to be made available in the United States, and he worked within the medical and biological sciences to develop useful applications of the electron microscope in those fields. Hillier eventually held more than forty patents for devices and processes for improving the fields of electron microscopy, electron diffraction, electron microanalysis, ultrathin sectioning, and virology and bacteriology. Among the most important patents he obtained were those for the electron microscope, the electron microanalyzer, the electron probe analysis employing X-ray spectrography, the method of and means for correcting for distortion in electron lens systems, the method of operating electron guns, the correction device for electron lenses, and the method and apparatus for electronically determining particle size distribution.

In 1942, Hillier was transferred to the RCA Laboratories at the David Sarnoff Research Center in Princeton, New Jersey, where he worked for the majority of his career, barring two brief periods: 1953 to 1954, when he was employed by another firm, and 1955 to 1956, when he was employed as the chief engineer of RCA Industrial Electronics Products in Camden. Having developed the electronmicroscope in its practical form, Hillier sought to introduce the electron microscope into general use as a new and powerful research tool, particularly for the biological and medical sciences as well as for metallurgical research studies. Hillier developed the electron microscope by pursuing engineering improvements in the instrument and developing new techniques for the preparation of biological specimens. During this exploratory and developmental phase, he invented the electron microprobe. In addition to his work on the electron microscope, Hillier also supervised the development of RCA's VideoDisc, a precursor to the digital video disc (DVD).

THE ELECTRON MICROSCOPE

The first operative electron microscope was built in 1933 by German scientists Ernst Ruska and Max Knoll. Ruska and Knoll's microscope demonstrated all the principles of an electron microscope but could only magnify objects up to four hundred times. Further experiments later produced an electron microscope with resolution superior to a traditional optical microscope. In 1938, James Hillier and Albert Prebus, graduate students at the University of Toronto, created the first practical commercial electron microscope based on the work of Ruska and Knoll.

The electron microscope uses a particle beam of electrons to illuminate a sample and thus create a highly magnified image. Far superior to traditional light microscopes, modern electron microscopes utilize electromagnetic radiation and can magnify objects up to two million times. The electron microscope is capable of greater resolution and magnification because of the electron's wavelength, which is much smaller than that of a photon. The electron microscope controls an electron beam using electrostatic and electromagnetic lenses to form an image by focusing the beam at a specific plane relative to the sample in much the same way that an optical microscope uses glass lenses to focus light on or through a specimen to form an image.

Although modern electron microscopes can magnify objects up to two million times, they are still based upon Ruska's prototype, later perfected by Hillier and Prebus. The electron microscope has become an essential piece of equipment in many hospitals and laboratories around the world. Such microscopes are used to examine biological materials (such as microorganisms and cells) and a variety of large molecules, to detect cancer or tumors in humans and animals, and to examine metals and crystalline structures as well as the characteristics of various surfaces. More recent applications of the electron microscope include its use in inspection and quality assurance in industry, particularly semiconductor device fabrication.

In 1945, Hillier coauthored *Electron Optics and the Electron Microscope*. During his career, he contributed numerous chapters and articles to scholarly texts, including the *Encyclopedia Britannica*, and more than 150 technical articles published in various professional journals.

In 1960, Hillier was corecipient, with Ernst Ruska of the Technical University in Berlin, of a Lasker Award, conferred jointly by the American Public Health Association for their separate work on the design, construction, and perfection of the electron microscope as an essential tool of modern medical research. In 1967, he was elected to membership in the National Academy of Engineering. Hillier eventually rose to wield corporate responsibility for all of RCA's research, development, and engineering programs. In 1980, Hillier was inducted into the National Inventors Hall of Fame for his development of the electron microscope. On April 17, 1997, he was appointed an Officer of the Order of Canada for this invention.

In keeping with his scientific and academic contributions, Hillier was a fellow of the American Physical Society, the American Association for the Advancement of Science, and the Institute of Electrical and Electronics Engineers. He was a member of the Electron Microscope Society of America (president, 1945), the National Academy of Engineering, and the American Management Association. He died on January 15, 2007, in Princeton.

IMPACT

Hillier and Prebus created the first practical electron microscope in North America based on the previous work of German researchers, who had been able to magnify objects by only four hundred times. Unfortunately, this magnification was within the range of traditional optical microscopes at that time. Hillier and Prebus's electron microscope managed to magnify objects seven thousand times their size by sending a stream of electrons through magnetic coils. This magnification was three times that of optical microscopes.

Hillier dedicated his research to producing a compact microscope that would be both more affordable and more effective for biomedical research than the bulky and expensive prototype. Early efforts at using the electron microscope for medical applications (such as microorganism and blood cell analysis) resulted in the destruction of the specimens by the powerful electron beam. With the help of others, Hillier developed successful methods using protective colloid film to prepare samples, thus allowing bacteria and cells to be viewed and analyzed, and eventually leading to the use of electron microscopy in biopsies.

Later in his career, Hillier helped correct the problem of astigmatism in the lenses used in the electron microscopes, and he worked on the development of a scanning electron microscope that was capable of producing even higher resolution images. Hillier's work on the refinement and application of the electron microscope has had a dramatic effect on the growth of many of the biomedical sciences, including virology, biology, immunology, cytology, and genetics, as well as the geological sciences.

—*Sally A. Lasko*

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See also: Gerd Binnig; Philo T. Farnsworth; Dennis Gabor; Heinrich Rohrer; Ernst Ruska; Vladimir Zworykin.

DOROTHY CROWFOOT HODGKIN

English chemist

Hodgkin was an extraordinarily skilled and intuitive X-ray crystallographer who worked out the structure of cholesterol, penicillin, vitamin B_{12}, and insulin. She won the Nobel Prize in Chemistry in 1964.

Born: May 12, 1910; Cairo, Egypt
Died: July 29, 1994; Shipston-on-Stour, Warwickshire, England
Also known as: Dorothy Mary Crowfoot (birth name)
Primary field: Chemistry
Primary invention: X-ray crystallography

EARLY LIFE

Dorothy Crowfoot Hodgkin was born in Cairo, Egypt, on May 12, 1910. Her parents were John Winter Crowfoot, a supervisor of schools and antiquities for the British government, and Grace Mary (Molly) Hood, a self-taught botanist and botanical illustrator. Until she was four years old, she stayed with her parents and only occasionally visited England, but when World War I began, her parents left her in England with her sisters and a nursemaid. Only when the war ended four years later did her mother return to England to stay with her daughters.

Dorothy attended several private schools. When she was ten, she took a class that used a chemistry book that gave directions on how to grow copper sulfate crystals, which she made at home. At the time, chemistry was considered a suitable science for girls and women to study, and some chemistry sets were made especially for them. Dorothy got one and became fascinated with crystals and their regular, three-dimensional shapes.

While staying with her parents in the Sudan when she was thirteen, Dorothy met soil chemist A. F. Joseph, who helped her analyze a crystal she had found. He was so impressed by her that he gave her a surveyor's box and encouraged her to study analytical chemistry. Her mother later gave her a book on X-ray crystallography by William Henry Bragg that became her inspiration for her lifelong career.

Dorothy graduated from high school in 1928. She hoped to attend Oxford University to study chemistry, only to discover that she was not qualified for admittance because she had not studied Latin or a second science. Her mother taught her botany, and she studied Latin on her own and finally passed the entrance exams. Her gender severely restricted her life at Oxford, as there were strict limits on subjects female students could study or what they could attend socially. Here she began her studies of X-ray crystallography in earnest.

LIFE'S WORK

In 1932, after her graduation, Hodgkin was unable to find work. A. F. Joseph, the chemist she met in the Sudan when she was thirteen, suggested that she work for John Desmond Bernal at Cambridge University. With a grant for £75 and a gift of £200 from her aunt, Hodgkin was able to work with Bernal for at least one year. One day in 1934, Bernal succeeded in taking the first X ray of a protein crystal. Hodgkin was diagnosed with severe rheumatoid arthritis, which eventually crippled her hands and feet terribly.

In 1936, Summerville College, the women's college at Oxford, offered Hodgkin a teaching position after she finished another year with Bernal. She stayed as a research fellow at Summerville until 1977. In spite of her horrendous laboratory space in the basement of the Oxford University Museum with its antiquated equipment, Hodgkin began studying cholesterol and succeeded in describing its three-dimensional structure.

One of the difficulties in interpreting the X rays was calculating the distribution of the atoms in the crystals. A. L. Patterson, a physicist, developed an intricate set of calculations to do this. Thousands of tedious calculations were needed to figure out the arrangement of atoms in even a simple crystal, so Hodgkin was thrilled when C. A. Beevers and H. Lipson sold her two boxes containing 8,400 strips of paper that were preprinted with trigonometric values that reduced the Patterson equations to simple addition. Hodgkin also found that substituting one element for another in a complex crystal and then comparing the X rays of each gave her additional information about the element's placement. Looking at hundreds of X rays had also helped Hodgkin develop an intuitive sense of what she was observing.

Dorothy married Thomas L. Hodgkin in December, 1937, when she was twenty-seven. They had three children: Luke, Elizabeth, and Toby. Thomas appreciated Dorothy's work and encouraged her to continue. With his help, Dorothy was able to juggle her career and motherhood. A side benefit of having her children was that her arthritis greatly improved while she was pregnant.

At the beginning of World War II, Dorothy Hodgkin began deciphering the structure of penicillin. She believed that knowing its structure would enable its manufacture, as it would be sorely needed to fight infection among the wounded troops. Although penicillin is a small molecule, the molecules can align themselves in many patterns when they crystallize, making X-ray analysis very difficult. Nevertheless, along with her graduate

Dorothy Crowfoot Hodgkin. (©The Nobel Foundation)

X-RAY CRYSTALLOGRAPHY

Before the development of X-ray crystallography, chemists were able to determine what atoms in what ratios made up a complex molecule, but they could not determine the three-dimensional placements of these atoms. X-ray crystallography and Dorothy Crowfoot Hodgkin's contributions to the science made determining complex molecular structures possible.

X rays were discovered in 1895 by Wilhelm Conrad Röntgen, and X-ray crystallography was first used at the beginning of the twentieth century. X rays are directed at a crystal, and the beams are scattered in specific directions by the electrons in the molecules. The scattered beams appear as spots on the X-ray film, making a diffraction pattern. The crystallographer then measures the angles and intensities of the patterns and through a series of calculations can determine the density of the electrons in the crystal. The positions of the atoms can be determined from the positions of the electrons. At first, X-ray crystallography was used to determine the bond types of simple inorganic compounds such as the ionic bonds in table salt and the tetrahedron structure of the carbons in diamonds. It was also used to determine the arrangement of atoms in minerals and metals. Later, the technique was applied to simple inorganic compounds such as hexamine, which contains twenty-two atoms.

The use of X-ray crystallography to solve the structures of complex biological compounds was very much the innovation of Hodgkin. She used Linus Pauling's rules for how atoms form crystals based on their electrical charges and for determining approximate sizes of atoms as a starting point. In large molecules that had one unique atom, she developed a technique to locate the specific atom by a substituting a different atom in the molecule and using the change this made on the X rays to pinpoint the atom's position. She used this technique to determine the position of the cobalt atom that was in a cyanide group in vitamin B_{12}. She replaced the cobalt with an atom of selenium, took X rays of the new crystal, and compared the results with X rays of vitamin B_{12}. Her studies of crystals led to her discovery of the hitherto unknown corrin ring, which proved to be a major contribution to organic chemistry.

Calculations were essential to computing positions of atoms in a molecule. At first, Hodgkin used A. L. Patterson's computations, her Beevers-Lipson paper strips, and maps of electron densities that she drew based on the computations to determine the structures of the compounds, but this was tedious and slow. She was one of the first to recognize the importance of computers, and as computers developed, she was able to exploit their growing power to perform the complex calculations much more rapidly than she could do using the Beevers-Lipson strips. The development of the computer allowed Hodgkin to determine electron densities for increasingly complex biological molecules. Largely because of her pioneering work, X-ray crystallography continues to be an important tool for chemists working on complex molecules.

student Barbara Rogers-Low, Hodgkin worked out the structure. The two performed their mathematical analyses on an early analog computer from International Business Machines (IBM) that was being used during the day to track British cargo ships, but they were allowed to use it at night, giving the keypunchers data in which the atoms of the penicillin molecule were labeled as cargo shipments. As computers improved in the following decades, their use became invaluable to X-ray crystallographers.

As knowledge of her ability as an X-ray crystallographer spread, both Hodgkin's career and laboratory facilities grew. In 1947, she became the third woman to be elected to the Royal Society of London. She moved into a modern laboratory in 1958, and in 1960 the Royal Society procured for her an endowed chair at Oxford, the Wolfson Research Professorship.

In 1948, a representative of a drug company gave Hodgkin some vitamin B_{12} crystals to analyze. It was known that B_{12} combats pernicious anemia, but without its structure the company could not manufacture it in quantity. Six years and twenty-five hundred X rays of the crystal later, Hodgkin had a massive bank of data but could not analyze it with only her Beevers-Lipson strips. A professor from the University of California, Los Angeles, offered her use of his high-speed computer; via telegrams, letters, and phone calls between England and California, the computations were completed and the structure of B_{12} worked out.

In 1964, Hodgkin won the Nobel Prize in Chemistry for her work. For most of her career, Hodgkin had tried to decode the structure of insulin, a huge molecule composed of 777 atoms. Now that computers were sophisticated enough to handle the massive calculations needed to analyze the X rays, Hodgkin decided to have another go at insulin. In 1969, she published its structure.

Throughout her life, Hodgkin had been an advocate for world peace and harmony, and in her later life her political views created problems with her scientific pursuits. In the Cold War years, she helped organize the International Union of Crystallography so that crystallographers worldwide could share information regardless of the country they lived in or their political views. When they tried to meet in the United States, the United States would not admit Eastern Europeans or Soviets into the country. In 1953, Linus Pauling hosted a conference on protein structures in the United States, but the State Department would not grant Hodgkin a visa because of her communist leanings. Her attempts to bring countries together in peace was not all for naught. Margaret Thatcher, the prime minister of Great Britain from 1979 to 1990, was one of her former chemistry students, and in the late 1980's Hodgkin wrote to her suggesting she visit the Soviet Union to improve relations between the Soviets and Great Britain. Thatcher did, and her visit was fruitful.

Hodgkin retired in 1977 to her home in a village north of Oxford. She died in her home on July 29, 1994, at the age of eighty-four.

IMPACT

Hodgkin's contributions to chemistry are basically twofold. First, her lifelong work in X-ray crystallography created major advancements in the field and proved that the technique could be used successfully on huge molecules such as proteins, hormones, and vitamins. Second, her discoveries of structures of vitamin B_{12}, insulin, and penicillin helped other researchers better explain their functions and allowed for their synthesis in mass quantities.

Robert Burns Woodward at first disagreed with Hodgkin on the structure of penicillin, thinking that it was a tricyclic structure containing a thiazolidine ring, but Hodgkin proved through her X-ray crystallography that it actually contained a beta-lactam ring. Her description of the actual structure allowed Woodward to produce a semisynthetic version of penicillin. After Hodgkin had deciphered the structure of vitamin B_{12}, Woodward began work on synthesizing it. It took eleven years, but finally Woodward succeeded. His work led to the development of the Woodward-Hoffman rules to predict the stereochemistry and symmetry of molecules and led to a Nobel Prize for Woodward.

Hodgkin described the structure of pig insulin, which differs from human insulin by one amino acid. Her description of the structure of the hormone led to a better understanding of how the molecule actually functioned. Her work allowed manufacture of synthetic insulin in the 1980's, although later production of human insulin was made possible by recombinant DNA synthesis.

—*Polly D. Steenhagen*

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See also: Wilhelm Conrad Röntgen; Max Tishler.

RICHARD MARCH HOE

American mechanic

Hoe was a manufacturer and inventor of printing presses in nineteenth century New York City. His cylinder rotary presses for printing newspapers were so much speedier than the older flatbed models that they have been credited with helping create the modern world of mass-produced journalism.

Born: September 12, 1812; New York, New York
Died: June 7, 1886; Florence, Italy
Primary field: Printing
Primary invention: Rotary printing press

EARLY LIFE

Richard March Hoe was born to Robert and Rachel Mead Smith Hoe in New York City in 1812. Richard was their fourth child and oldest son. He attended New York's public schools until he was about twelve, when he went to work in his father's pattern shop. After eighteen months of work, he returned to high school. At the age of eighteen, Hoe began working in his father's factory. Robert Hoe had started a company for printing presses, long and circular saws, and other tools with his brother-in-law Peter Smith in 1805. Robert and Peter manufactured two kinds of presses, the cast-iron "Smith" and the platen "Washington." Both presses operated on a flatbed model in which a roller traveled backward and forward inking the paper. At the time Richard joined the firm, Robert Hoe was experimenting with cylinder presses. Richard inherited his father's mechanical ability and his ingenuity as to both the manufacturing and business aspects of Smith, Hoe & Co.; he also received a thorough education in every aspect of the enterprise. During the 1830's, Richard Hoe served as commander of the New York National Guard unit, the Washington Greys, achieving the rank of colonel, the title by which he would be known throughout his life.

LIFE'S WORK

Robert Hoe, in declining health, retired in 1830, leaving management of the factory to Richard and Peter Smith's son Matthew. Richard Hoe immediately set about improving the printing presses along the lines of a cylindrical operation with which his father had begun experimenting. In 1833, he introduced a single-cylinder press, adapted from presses operating in England. This press operated on a flatbed, but Hoe set the type in a fixed cylinder, with impression cylinders that held the sheets of paper and rotated around the type. Hoe also patented a novel method for grinding circular saws, which gained widespread usage.

In 1837, Hoe made further progress in the use of cylinders in his presses, introducing a double small-cylinder press and a single large-cylinder press. These presses were very popular and were used for books, prints, and woodcuts. Nevertheless, the firm was often short on funds and in 1842 went temporarily bankrupt. Hoe's innovations continued, however. In 1844, he developed an adjustable type-high bearer on each side of the press bed, which improved the press's impression control. In the late 1840's, he developed methods for heating ink fountains so as to enhance viscosity, a double rack and sliding pinion drive mechanism, and a sheet delivery system called a flyer. He also patented new devices for toothing and grinding saws.

Hoe continued to experiment on a high-speed press that would satisfy the need for quickly produced newspapers. His great breakthrough came in 1846 with his invention of the four-cylinder rotary press—the "lightning"—making use of a central revolving cylinder with type-beds and four rotating impression cylinders. As each impression cylinder was able to print two thousand sheets an hour, the four-cylinder rotating press was able to print eight thousand sheets in that time. Over the next few years, Hoe continued to improve his rotary press until it could run with ten impression cylinders. The press had become a massive machine, more than twenty feet high and thirty feet long, staffed by a crew of about fifteen workers running the machine and feeding sheets of newsprint. As the ten-cylinder press was able to make twenty thousand paper impressions an hour, it was quickly adopted throughout the world.

Matthew Smith died prematurely in 1841, and Hoe's younger brothers, Robert Hoe II and Peter Smith Hoe, joined R. Hoe & Company under Richard Hoe's leadership. Hoe built a new factory between Broome and Grand Street, taking up an entire New York City block and covering more than four acres of floor space. Hoe was a farsighted employer, establishing a free apprentice school at night for his employees, a mutual relief society for disabled workers, and cooperative stores supplying goods for his employees at reduced prices. With his factory profits, Hoe became wealthy, branching out to Chicago and London. He also continued to improve his presses, introducing a stop-cylinder press for litho-

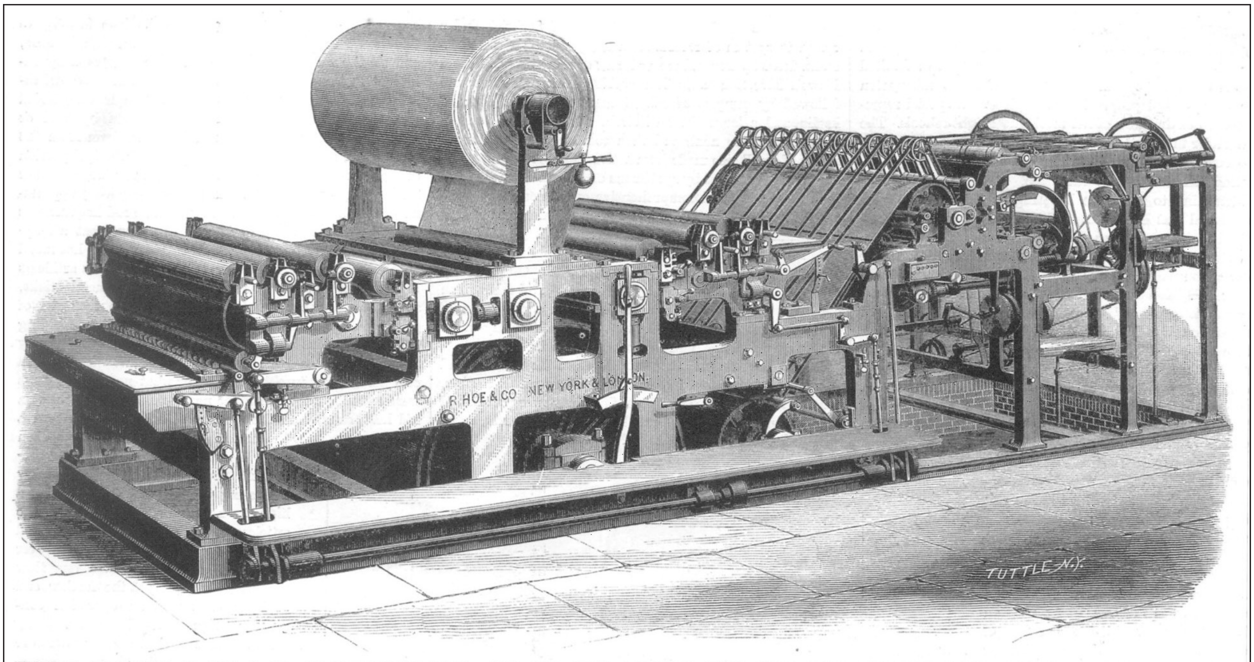
R. HOE & CO NEW YORK & LONDON.
TUTTLE N.Y.

EXHIBIT OF MESSRS. R. HOE & CO., IN MACHINERY HALL.—THE HOE PRESS, PRINTING BOTH SIDES FROM THE ROLL, WITH FOLDING MACHINE ATTACHED.

The Hoe rotary printing press, which was exhibited at the 1876 Centennial Exhibition in Philadelphia. (The Granger Collection, New York)

graphic and letter-press printing and a collecting cylinder, called an accumulator, in 1853. In 1871, making use of a gathering and delivery device invented by his partner Stephen Tucker, Hoe designed a press that printed from a continuous roll, or web, of paper. This press represented a significant advance because it could automatically feed paper and print on both sides. As a result, it was able to print eighteen thousand newspapers an hour. In 1881, the company introduced a triangular former folder.

Throughout his career, Hoe demonstrated that he was capable of combining his mechanical aptitude with shrewd and adroit industrial management. Acquiring the Isaac Adams Press Works in Boston in 1859, he successfully integrated its operation into his New York plant. He utilized the innovations of his partners, such as Tucker, and competitors, such as William Bullock of Philadelphia, who first patented the web press. Hoe's printing presses won two awards at the famous 1876 Centennial Exhibition in Philadelphia. His branches in San Francisco, Chicago, and England thrived, as did his London repair shop. As a magnate and philanthropist, Hoe bought real estate, served as a director of the Magnetic Telegraph Company, and supported the New York House of Refuge.

Hoe had two daughters, Emily (born 1834) and Adeline (1836), with his first wife, Lucy Gilbert. After her death in 1841, he married Mary Say Corbin, with whom he had Anne (1852), Mary (1854), Fannie (1855), and Helen (1858). He named his stately home Brightside, located on fifty-three country acres in what is now the Bronx, and filled it with expensive works of art and fine, rare books. In 1886, on one of his frequent European trips, he died in Florence, Italy. His nephew Robert Hoe, who had worked for him for many years, took over the firm.

IMPACT

In a sense, the history of printing technology is the constant search for speedier printing presses. With mechanical skill and technological ingenuity inherited from his father, Richard Hoe was well suited to advance this search. His father's printing company had already been successful in producing cylinder presses, an important advance over the hand press. Hoe accelerated this development. His cylinder rotary presses reached a speed of twenty times that of his father's presses. Where it formerly took a day to print thirty thousand newspapers, it could now be done in two hours. It soon became apparent that it was more economical to produce mass-circulation newspapers by typesetting a single Hoe lightning press than by running several smaller machines simultaneously. As a result, his presses were adopted throughout the

United States, the English-speaking world, and Europe. Hoe's industrial success was counted as one of the first examples of the United States being able to compete against the industrial might of Britain and France. Over the following decades, R. Hoe & Co. continued to improve its presses, to the great satisfaction of the publishing world. His web perfecting presses of the 1870's were able to print both sides of a page in a single impression.

Richard Hoe was the owner of a factory and was himself one of the chief innovators and inventors in his industrial field. In this way, he resembles other American inventors of the nineteenth century, such as Peter Cooper, Thomas Alva Edison, and Samuel F. B. Morse, who also combined entrepreneurial leadership and mechanical invention to reach industrial and scientific success and great wealth. Whether this combination of business and invention in the nineteenth century was a uniquely American phenomenon—or in the case of Hoe and Cooper, a uniquely New York one—is worth investigating.

With the rise of Jacksonian democracy in the 1830's, the United States entered its golden age of newspapers. The common people were made aware of political developments, social events, and the bustling progress of the industrial world through a proliferation of inexpensively produced and widely circulating newspapers. Great newspaper enterprises were founded by such men as Horace Greeley, Joseph Pulitzer, and William Randolph Hearst. This golden age of journalism, so integral to the growth and democratization of the United States, relied to a large extent on the technological advances in the printing presses of Richard Hoe and his company.

—*Howard Bromberg*

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THE HOE FOUR-CYLINDER ROTARY PRESS

Richard March Hoe's four-cylinder rotary press—the "lightning"—represented a revolutionary advance in printing. The earlier cylinder presses, resting on a flatbed, were able to print only one page with each back-and-forth rolling motion. Hoe's breakthrough was replacing the flatbed with a large rotating cylinder against which the paper would roll. He fastened cast-iron typeset around the circumference of the horizontal cylinder and grouped four smaller impression cylinders around the central cylinder. As the impression cylinders rotated around the central cylinder, each was able to impress two thousand sheets an hour. Two inking rollers distributed ink to the large type cylinder. Workers at each end, usually boys, fed the sheets into the impression cylinders; a crew of some ten men worked the machine. The speed of the printing could be accelerated by increasing the speed of the revolving central cylinder and by increasing the number of impression cylinders, which eventually reached ten. Thus the rotating press was able to increase the speed of newspaper printing by about an order of twenty.

After several years of development, Hoe patented his rotary press—also known at the time as the lightning printing press, the Hoe perfecting press, and the cylindrical-bed press—on July 24, 1847 (U.S. Patent number 5,199). It was first installed at the Philadelphia Public Ledger Office in March, 1847. It was by far the most efficient press for printing newspapers in its day and created a sensation. The press was speedily adopted in England; the British Privy Council called the "lightning" the "greatest step" taken in the art of printing. The *New York Sun* ordered a rotary press in 1849 for $20,000 and held a banquet in New York's Astor House to celebrate the occasion. When the *New York Tribune* installed its rotary press in 1850, it was the ninth made by the Hoe company. Soon Hoe was selling six- and ten-cylinder rotaries for about $25,000 a machine. In July, 1861, Hoe's patent for his rotary printing press was renewed for a seven-year term, the patent office concluding that additional millions of dollars would be made from the machine, in addition to the $78,681 already realized. Historian of the printing press James Moran described the rotary press as revolutionizing printing, not only for its speed but also for replacing a skilled printer at the helm with a mechanic or engineer. In this way, the rotary press symbolized the industrial age, when mass mechanical production replaced the work of a craftsman.

The cylinder rotary press remained the industry standard for several decades until the development of a machine that could print a continuous roll, or web, of paper. Even then, Hoe was able to adapt the techniques of his rotary press to the new machine. With the help of Stephen Tucker, R. Hoe & Co. manufactured a web press in 1873 that could print, cut, and deliver eighteen thousand newspapers an hour. In 1875, Tucker patented a rotating folding cylinder that could fold newspapers as soon as they emerged from the press. With these several decades' worth of improvements to Hoe's original four-cylinder press, Hoe's company was manufacturing the first modern newspaper printing presses.

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See also: William Bullock; Johann Gutenberg.

TED HOFF

American engineer

Hoff placed the entire circuitry of a computer's central processing unit (CPU) on a single chip that could be mass-produced by photolithographic methods. His development of the microprocessor made the digital revolution possible.

Born: October 28, 1937; Rochester, New York
Also known as: Marcian Edward Hoff, Jr. (full name)
Primary field: Computer science
Primary invention: Microprocessor

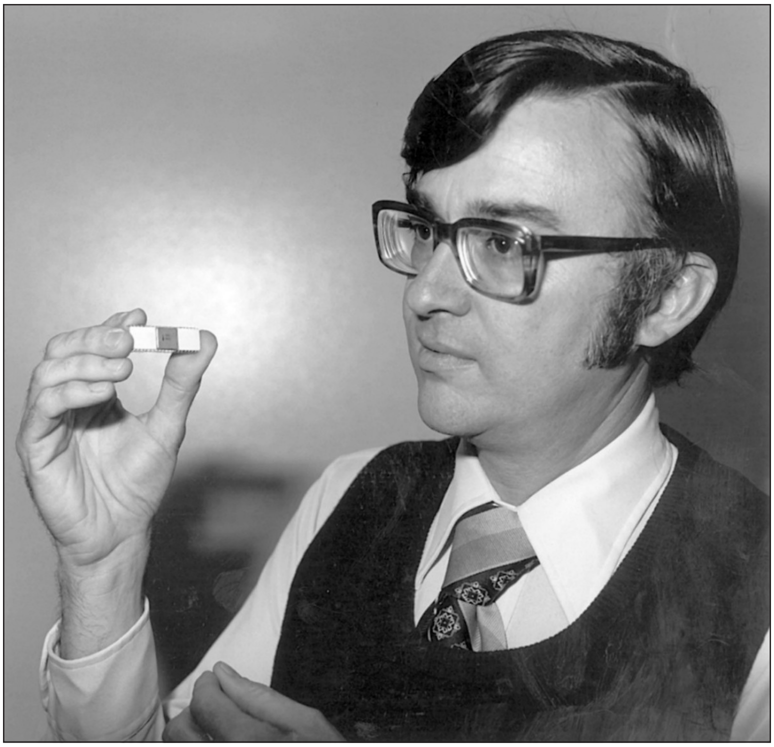
EARLY LIFE

Marcian Edward Hoff, Jr., was born in Rochester, New York, on October 28, 1937. His education began in a one-room schoolhouse near the village of North Chili, not far from Rochester. There, a single teacher would instruct the children in all eight grades. In this setting, Hoff was exposed to the work done by older students, and it was relatively easy for him to move to more advanced work even if his classmates were not yet ready.

Hoff's father worked for the General Railway Signal Company, which produced and maintained the signal system that allowed trains to function smoothly. The elder Hoff talked about his work with his son, awakening in him an early fascination with electronics. Hoff's uncle showed him the wonders of chemistry, once pouring two clear liquids together and making them turn bright red. Hoff found the phenomenon so fascinating that he voraciously read everything he could about chemistry, and he took the New York State chemistry examination on the basis of his independent work, scoring very high. However, his uncle warned him that there were few jobs for chemists and that he would be better off studying chemical engineering.

Hoff decided instead to apply his knowledge of chemistry to the newly developed field of semiconductor electronics. At Churchville-Chili Central High School, he maintained an avid interest in electronics and at age fifteen won a $400 scholarship and a trip to Washington, D.C., from the Westinghouse Science Talent Search. In 1954, he entered Rensselaer Polytechnic Institute, one of the oldest technological institutions in the United States. His fellow students would later recall him as a brilliant and inquisitive person, but never one to flaunt his intellect or belittle others. More than once he would finish projects at the last minute but still turn out excellent work. During his summers, he worked with General Railway Signal Company, where his contributions to two different projects led his name to be included on the patent applications.

After he earned his bachelor's degree in 1958, Hoff went to Stanford University for his master's degree and doctorate, specializing in electrical engineering. He continued to do practical work, leading to two more patents in his name. His doctoral dissertation was on neural networks and learning. After earning his Ph.D. in 1962, Hoff spent another six years as a research associate at Stanford.



Ted Hoff holds a microprocessor chip he invented at Intel. (Intel)

LIFE'S WORK

In 1968, Hoff became the twelfth employee at Robert Norton Noyce and Gordon E. Moore's new start-up company, Intel. Noyce was impressed with the practicality of Hoff's academic research and was hoping that Hoff would be able to develop commercial applications for the integrated circuits that Intel was making. At the time, the integrated circuit was relatively simple. Once the processes it would run were burned into its circuitry, it was capable of doing only that one thing. As a result, devices based on integrated circuits required a large number of circuits, one for each process or function. For simple functions such as basic bookkeeping mathematics, mechanical adding machines were still more cost-effective, although they were prone to breakdown as their gears wore down with use.

While working on an assignment for a Japanese calculator company, Hoff began to see the limitations of the integrated circuits. To build a complex, multifunction calculator with hardwired chips would tax the abilities of the entire team at Intel. There were simply too many chips that would have to be designed. If instead it was possible to design a chip that could read programs from memory, execute them, and then remove them when finished, this single chip could do hundreds or even thousands of different functions. It would be easy to create a machine that could do almost any range of functions, limited only by the amount of memory included in the memory chips.

Noyce encouraged Hoff to continue exploring the idea even after the commissioning company showed little interest in it. With the aid of fellow employee Federico Faggin, who designed the actual chips themselves, Hoff developed an entirely new architecture for integrated circuits. This new design took all the circuitry of a computer's central processing unit (CPU) and etched it onto a single piece of silicon. The resultant chip contained 2,300 transistors and had a computing power equal to that of the Electronic Numerical Integrator and Computer (ENIAC), the first general-purpose electronic computer. Moreover, while ENIAC and its ilk required a cabinet the size of a desk to hold all CPU circuitry, Hoff and Faggin's microprocessor chip was hardly bigger than a human thumbnail. Even with the protective ceramic casing and the lead wires for its socket, it was still hardly bigger than a postage stamp.

However, Noyce and Moore knew that the development of the CPU chip, which they called the Intel 4004 (released in 1971), was not an unbeatable coup. Thus, Hoff's team was set to work on a successor chip, the 8008 (introduced in 1972), which contained twice as many transistors and was faster than its predecessor. In 1980, Hoff was made an Intel Fellow, the highest technical position at Intel. However, in 1983 he left Intel to become vice president of corporate research and development at Atari, which had gained its reputation in the arcade game industry and subsequently expanded into console game systems for home use. At the time, Atari was starting to build machines that went beyond gaming to include general-purpose computing functions. However, Atari was already in financial trouble, and a year after Hoff moved, it was sold. Hoff found the new management less than congenial to his interests, so he left to start his own consulting firm, setting up an office and lab in the garage of his Sunnyvale home. He found consulting particularly agreeable because of the freedom it afforded him: He

THE MICROPROCESSOR

The microprocessor is the key technology of the digital revolution, much as the steam engine was central to the Industrial Revolution. The microprocessor is an outgrowth of the integrated circuit, which in turn was a response to the "tyranny of numbers" that developed as transistors replaced vacuum tubes. Because discrete transistors were so small, it was very difficult to solder all of them into a circuit board properly. If the transistors could all be made together on a single wafer of silicon along with the necessary circuitry to connect them, the only limits to the complexity of a circuit was the ability of chip designers to lay out the masks for the photolithography, the main process used to create microchips.

When Intel was approached by the Japanese corporation Busicom to design the chipset for a new electronic calculator, Ted Hoff saw several ways to simplify the design, combining single-function integrated circuits into more complex ones. Eventually, he was able to reduce the design to three chips, a read-only memory chip in which key functions would be hardwired, a random-access memory (RAM) chip to provide the calculator's working memory, and a central processing unit (CPU) in which actual calculation would be carried out.

Intel chief executive officer Robert Norton Noyce immediately recognized the value of the microprocessor design, but the terms of the agreement by which Intel had undertaken the project assigned all rights to the chips to Busicom. However, Busicom soon ran into financial difficulty, and as a result Intel was able to buy back the rights to what would become the 4004 microchip, the first "computer on a chip," which Intel publicly introduced on November 15, 1971. Even as general production was begun, Hoff and his team were already hard at work designing its successor, the 8008.

Subsequent processors would include the famous X86 family, including the Pentium and the Xeon, as well as Motorola's 68000 and PowerPC chip families. The microprocessor made the personal computer (PC) possible, and microcomputers were designed from the microprocessor chip, generally by young hobbyists such as Apple Computer cofounders Steve Wozniak and Steve Jobs rather than by the corporate interests that built mainframe computers. Only when companies such as Apple Computer proved the market for the microcomputer did International Business Machines (IBM) move into that niche with the 8088-based PC.

The utility of the microprocessor was not limited to general-purpose computing. By the 1990's, microprocessors were increasingly used in runtime applications as microcontrollers, embedded devices that imparted "intelligence" upon ordinary appliances. They enabled many ordinary things to work more efficiently. For instance, embedded controllers could regulate the functions of the engine of an automobile far more accurately than mechanical systems, thus greatly increasing fuel economy. In addition, they made possible such devices as cellular phones, CD and MP3 players, and handheld organizers.

could pick projects of interest to him without having to justify them to corporate management.

In 1986, Hoff decided to return to the corporate fold, becoming vice president and chief technical officer with Teklicon, a company specializing in expert witnesses for patent infringement litigation cases. However, he continued to maintain his home laboratory and to work in his spare time on various projects. Hoff has received a wide variety of honors, including the IEEE Computer Society Pioneer Award, the Rensselaer Polytechnic Institute's Davies Medal, the Stuart Ballantine Medal from the Franklin Institute, and induction into the National Inventors Hall of Fame.

IMPACT

Hoff's creation of the microprocessor revolutionized the computer industry. For the first time, a single piece of silicon could be a general-purpose programmable computer. The chip's small size and inexpensive manufacture placed computers within the reach of ordinary people for the first time and allowed the integration of computer technology into a wide variety of applications.

—*Leigh Husband Kimmel*

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See also: John Vincent Atanasoff; Federico Faggin; Steve Jobs; Jack St. Clair Kilby; Robert Norton Noyce; Steve Wozniak.

JOHN PHILIP HOLLAND

Irish American engineer

Holland was a submarine engineer who developed the USS Holland, *the first submarine to be commissioned by the U.S. Navy. His patents include many advances in submarine engineering, including screw propeller propulsion, steering apparatuses, engines, dive mechanisms, and guns.*

Born: February 29, 1840; Liscannor, County Clare, Ireland
Died: August 12, 1914; Newark, New Jersey
Also known as: Seán Pilib Ó Maolchalann
Primary fields: Military technology and weaponry; naval engineering
Primary invention: Modern submarine

EARLY LIFE

John Philip Holland (HAHL-luhnd) was the second of four sons born to John Holland and Máire Ní Scannláin (Mary Scanlon). His father was a rider for the Coastguard Service, giving young Holland an interest in boats at an early age. When his father and one brother were lost to the 1847 Irish potato famine, his mother moved her remaining family to Limerick. Holland attended the Christian Brothers School in Ennistymon and later the Sexton Street School in Limerick. Two strong influences on Holland were Brother Bernard O'Brien and Brother Dominic Burke. Brother O'Brien, one of his science instructors and an accomplished mechanic, built telescopes that used clockwork mechanisms to track movements of celestial bodies and expanded Holland's interest in mechanics. Brother Burke, a renowned science teacher, researched the use of electricity for underwater propulsion. Burke encouraged Holland's investigations of both submarines and flying machines.

When asked to teach for the Christian Brothers, Holland accepted, joining the Order of the Irish Christian Brothers as Brother Philip. He taught at several schools throughout Ireland. In 1869, while teaching in Dundalk, he developed his first submarine design. In 1872, Holland reached the point where he would have to take his perpetual vows or leave the order. His mother and brother Alfred had already left Ireland for the United States, and Holland decided leave the Christian Brothers behind to follow them, departing Liverpool on May 26, 1873, for Boston, Massachusetts.

LIFE'S WORK

Holland's brother Michael was a member of the Fenian Brotherhood, a group of militant Irish nationalists, and in 1876 he induced Holland to help the Fenians develop a submarine that could be carried aboard a merchant ship, launched with its three-man crew through an underwater door, place an underwater explosive beside a British vessel, and then return to base. Holland built the *Fenian Ram* at the Delamater Iron Works in New York, and it was launched in May, 1881. It was thirty-one feet long and could cruise at nine miles per hour on the surface and seven miles per hour underwater. Much of the mechanisms on the submarine operated using compressed air, including the underwater pneumatic gun. When Holland and the Fenians disagreed over his payment, the Fenians stole the *Fenian Ram* and a sixteen-foot model of the submarine. Holland's relationship with the Fenians abruptly ended with this incident, and twenty years later, Holland sold his design to the British navy.

Following his debacle with the Fenians, Holland took a job as a draftsman with the Pneumatic Gun Company, owned by Army lieutenant Edmund Zalinski. With Zalinski, Holland formed the Nautilus Submarine Boat Company, named for the submarine in the Jules Verne novel *Twenty Thousand Leagues Under the Sea* (1870), which had been an inspiration to Holland. The fifty-foot-long "Zalinski Boat," officially named the *Holland IV*, was built at Fort Lafayette and completed in 1885. It was fitted with a petroleum-powered engine, a periscope, and Zalinski's compressed-air guns. The company planned to sell the boat to France to use in its war in Indochina, but the war ended before the boat's completion. Unfortunately, the wooden hull of the boat was damaged during its launch on September 4.

Holland and Margaret Foley were married in Brooklyn, New York, on January 17, 1887. Their first son, John, Jr., and later a daughter, Mary Josephine, died in infancy, but their three other sons and two daughters survived to adulthood.

In 1888, the U.S. Navy became interested in submarine technology and announced a competition for the design of a submarine that could stay submerged for two hours, withstand pressures to 150 feet, and run at fifteen knots on the surface and eight knots while submerged. Holland won the competition, but no contract was awarded. In 1889, the government reopened the competition, and once again Holland won. This time, the money that was to be awarded to Holland was diverted by a new administration to fund completion of naval ships that were already under construction. Once again, in 1889, the U.S. Navy held a third competition, which again Holland won. On March 3, 1895, the John P. Holland Torpedo Boat Company was given its $200,000 grant to build the submarine *Plunger*. Unfortunately, the money came with interference from Navy technicians who had many impractical specifications; for example, while Holland intended to use a diesel engine in the submarine, the Navy required that he install a steam engine, which produced too much heat and too little power. Their attempt to build the unworkable ship almost bankrupted Holland's company.

While building the *Plunger*, Holland, using private funds, began work on the gasoline-powered *Holland VI*. His new submarine, his own design built to his own standards, was a major improvement and set the stage for the construction of modern submarines. The *Holland VI* had dual-propulsion systems, two separate ballast systems, an improved hydrodynamic shape, and a modern weapons system. Holland offered to trade the ship's design to offset the *Plunger* debts, but the Navy refused, forcing Holland to sell his company. The new owners renamed it the Electric Boat Company. In 1900, the U.S. Navy did finally buy a modified version of the *Holland VI*, commissioned as the USS *Holland*.

Holland designed another submarine, the *Holland VII*,

THE *HOLLAND VI*

With a length of 53 feet, 9 inches, a diameter of 10 feet, 3 inches, and a displacement of 74 tons, the *Holland VI* was John Philip Holland's finest submarine design, incorporating many of the mechanisms and components of modern submarines: dual propulsion, ballast systems, hydrodynamic shape, a fixed center of gravity, and modern weapons systems. The concept of having one propulsion system to operate a submarine on the surface and another while underwater had been proposed before, but Holland developed the first practical system. On the *Plunger*, with the requirements the U.S. Navy imposed on its design, Holland had to use steam to propel the submarine on the surface, but the steam engine used up an inordinate amount of space and produced high interior temperatures that were intolerable to the crew. The *Holland VI*, on the other hand, was fitted with a diesel-powered engine that could charge the submarine's electric batteries while operating. When submerged, the submarine used an electric motor powered by batteries. The *Holland VI* could travel one thousand miles on the surface with its diesel engine and thirty miles underwater on battery power.

The *Holland VI* was the first submarine to use a main ballast tank to control its descent and surfacing, and a secondary system to adjust for changing loads and torpedoes. The submarine originally had three ballast tanks: a main tank, an aft ballast tank, and a trimming tank in the bow. When the submarine was overhauled in 1899, two additional trim tanks were installed in the aft section of the submarine. With the *Holland VI*, Holland abandoned his earlier symmetrical ship design for one in which the maximum diameter of the circular superstructure was forward of amidships. He also had his propeller in the centerline of the ship and forward of the rudders, a position that was not adopted by the Navy until the advent of nuclear submarines. Early submarines did not have a fixed center of gravity. With any change of angle of the submarine, the water in the ballast and boiler tanks would slosh in the direction of the lowest end of the vessel, aggravating the angle and making it very difficult to keep the submarine level while underwater. Holland's ballast system included main tanks that were filled completely so the water could not pool at one end or the other. The forward ballast tank was quite small, so allowing water to enter the tank had almost no effect on the longitudinal center of gravity of the submarine.

The *Holland VI* was fitted with a standard torpedo tube, and the Navy supplied two practice torpedoes for the crew to use during the trials of the submarine in 1898. While the *Holland VI*'s stability was touchy even with one man loading the torpedoes, the trials were successful and proved that torpedoes could be successfully launched underwater from a submarine.

in 1904, but was sued by the Electric Boat Company for patent violations and for using the Holland name on his new boat. Discouraged and lacking funds for either litigation or development costs, Holland retired from his submarine research. In his last years, he concentrated on designing a flying machine, but when the Wright brothers successfully flew their aeroplane, Holland gave up this work. He died of pneumonia on August 12, 1914, in the month that World War I began and his designs in naval submarine warfare were first put to use.

Impact

Holland has been called the "father of the modern submarine," and rightly so. He was fortunate to live at a time when there was rapid development of mechanization and industrialization. He was quick to see the utility of several of the new inventions and adapted them to his submarines. He used pneumatic power for control operations and to power his guns. He tried to use a steam engine to power a submarine but found that while the engine worked, it generated too much heat and too little power. He finally used diesel power, which was used to power submarines well into the twentieth century, when nuclear-powered submarines were introduced. His propulsion systems, hydrodynamic designs, ballast systems, and weapons systems were all used successfully, and in some cases are still used today.

—*Polly D. Steenhagen*

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See also: David Bushnell; Robert Fulton.

HERMAN HOLLERITH

American engineer

Hollerith invented tabulating machines using key punches to record data on cards, along with counting, sorting, and recording devices to process the data. After successful use in the 1890 census, his machines proved invaluable to governments and businesses all over the world.

Born: February 29, 1860; Buffalo, New York
Died: November 17, 1929; Washington, D.C.
Primary fields: Business management; industrial technology; mechanical engineering
Primary invention: Census tabulating machine

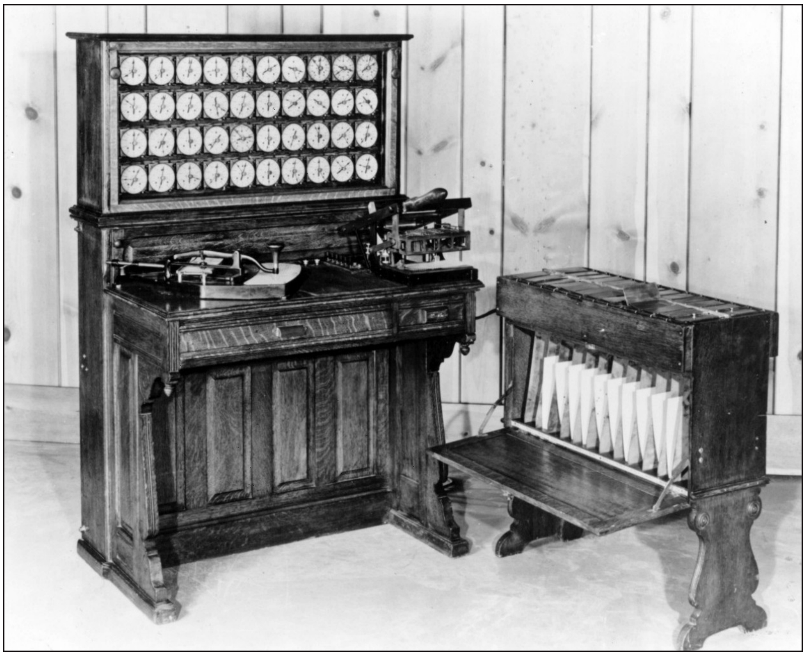
Early Life

Herman Hollerith's father fled Germany after the failure of the 1848 revolution and died when his son was seven. Hollerith stubbornly resisted attending public schools and was tutored privately by a Lutheran minister. He entered the City College of New York in 1875, then transferred to the engineering program at the Columbia University School of Mines, graduating with distinction in 1879. When one of his professors became chief special agent of the U.S. Census, he invited nineteen-year-old Hollerith to accompany him to Washington.

Hollerith worked at compiling statistics on manufacturing. On the side, he computed life tables as a favor for John Shaw Billings, director of vital statistics at the Census. Hollerith credited Billings with starting him on the task that would consume the rest of his life by casually saying that there ought to be a machine to carry out the mechanical work of tabulating population and other statistics. Hand-counting the steadily increasing population took so long that there were fears that future counts might not be completed until after the succeeding one began, rendering the census useless.

In 1882, Hollerith accepted a position at the Massachusetts Institute of Technology teaching mechanical engineering, but he discovered that he disliked teaching and left after one year. During his time in Boston, Hollerith considered various solutions to the problem Billings had posed. Appointed assistant patent examiner at the United States Patent Office in May, 1883, he once again left his position after one year. Hollerith, who always preferred to be in control, then opened an office as an expert consultant on patents. Hollerith's knowledge of patent law and procedures would prove invaluable in his career as an inventor.

Hollerith became engaged in 1885, but his fiancé died of typhus the following year. He would always thereafter be extremely solicitous about his family's health. He married in 1890 and fathered six children; Hollerith's three sons followed him into engineering careers.



Herman Hollerith's tabulating machine, patented in 1889 and used to compile the 1890 census. His machines accomplished in one year what would have taken nearly ten years of hand tabulation. (Getty Images)

LIFE'S WORK

Hollerith applied for his first patent for his census machine on September 24, 1884. It was granted on January 8, 1889, along with two other patents describing improvements on his first design. The basic idea was to pass nonconducting paper between electrically charged pins and a metal plate or drum. Electricity flowing through holes in the paper representing coded information activated electromagnetic counters, permitting rapid tabulation of data.

Hollerith first planned to use paper tape but soon decided that tape would make retrieval of single pieces of information a tedious and time-consuming task. Realizing cards could quickly be reread, he settled on cards the size of a dollar bill, which would fit easily available storage boxes. Holes punched on all four sides of the card with a handheld conductor's punch recorded the raw data. When punching cards by hand proved too slow and hard on the operator, Hollerith added a mechanical key punch, modeled after the typewriter; pressing keys punched appropriate holes in the card.

The director of the Census arranged test runs of Hollerith's machine tabulating mortality statistics in Baltimore in 1887, and later in New York City and New Jersey. In direct competition with two other machines, Hollerith's proved clearly superior and was chosen to compile the 1890 census. His invention was estimated to have saved the Census $5 million in labor costs. It completed in three months the simple head count that would have taken over two years by hand. In the next three years, Hollerith's machine produced, for the first time anywhere, a complete analysis of the census data. The Census preferred to rent machines rather than purchase equipment that would stay idle for most of the decade. Hollerith liked the idea: Since he owned the machines, he could prevent anyone from altering his invention. Leasing became the standard way Hollerith placed his machines.

His success with the 1890 census won Hollerith immediate international fame. The Franklin Institute of Philadelphia hailed his machine as the outstanding invention of 1890. Hollerith was invited to speak at the Royal Statistical Society in London in 1894 and International Institute of Statistics in 1895. His machines were used for censuses by Canada, Norway, and Austria in 1891, and subsequently in Russia, France, Germany, and Great Britain.

Hollerith modified his machine to accommodate the needs of an agricultural census and also sought to adapt the tabulators to the world of business, since this would provide a steadier source of income than census work. He custom-made his machines to suit the needs of railroad companies and for use in commercial bookkeeping, management control, and sales and cost analysis. In 1896, Hollerith incorporated his business as the Tabulating Machine Company, holding 502 of 1,000 common shares. To ensure card quality, Hollerith required that customers use only those his company manufactured. Profits from sale of cards exceeded income from machine leases.

In 1911, Hollerith agreed to sell his company to Charles R. Flint, who specialized in combining smaller companies into larger entities. Flint combined the tabulating company with a maker of computing scales and a manufacturer of time clocks into the Computing-Tabulating-Recording Company (CTR). Hollerith received $1,210,500 for his majority stock holdings. However, he was not ready to retire and insisted on a contract as a consultant for ten years at $20,000 per year, granting him a veto on any changes to his machines and stating that he was not to be subject to orders from anyone.

His veto power proved an irritant to Thomas J. Watson when he was hired to run CTR in 1914. Watson wanted to push development of improved tabulators, but despite careful diplomatic handling of Hollerith, sometimes found the stubborn inventor blocking changes needed to match competitors' machines. Watson would be embarrassed after World War II, when it became clear that the semiautonomous German subsidiary Hollerith established in 1910 was run by ardent Nazis who enthusiastically adapted the machines to aid management of the Holocaust. Hollerith retired in 1921. In 1924, Watson renamed Hollerith's company as International Business Machines (IBM).

Hollerith continued to invent after selling his company, mostly designing improvements to his tabulator. His last patent was granted in 1919; at the time of his death, he held thirty-one U.S. patents, as well as patents from eight foreign countries. However, Hollerith never patented his punch card with its clipped corner, since he did not think it was an original idea. In the 1920's, his attention focused on his Georgetown home, his farm, and a series of yachts. Hollerith died of a heart attack eight years after retiring.

HOLLERITH'S TABULATING SYSTEM

The tabulating machines Herman Hollerith provided the 1890 census had already developed beyond his original idea. His cards provided spaces into which the operator could use Hollerith's key punch to enter forty discrete items. Clipping one corner of the cards prevented their being entered upside down or backward. Once punched, the cards went to the tabulator machine operator, who used a hand-operated press. The upper portion of the press had retractable pins in each position where holes could be punched in the card. Wherever the press found a hole, the pins completed a circuit that moved a dial by one unit. The machine was not limited to counting only forty facts. Hollerith used electrical wiring on the back of the tabulator to connect two or more categories that were registered on separate dials. The first run of the cards produced seventy possible combinations of data.

Hollerith expanded the analytic capacity of his machine by using a sorting box divided into compartments. As the tabulator counted the seventy combinations, operators chose cards with certain characteristics, perhaps race or sex or citizenship, and placed them into the compartments to be run through the machine later. In 1890, the cards were run through the tabulator seven more times to complete the tables of correlations the census director desired. For the 1900 census, Hollerith provided a vertical sorter that automatically dropped the cards into the chosen boxes. The 1900 tabulator also incorporated an adding machine, permitting it to add quantities as well as count units.

In adapting his machine for commercial and industrial use, Hollerith had to change his cards to record numbers, rather than the specific items of information the census required. To do so, he modified his card to use the entire surface, not just the edges. He divided the card into vertical columns, each having the numerals from 0 to 9; groups of columns could be assigned as needed to record relevant numbers. In the New York Central Railroad's case, the first five columns of the card registered weights of shipments; additional columns recorded other data or prices. Hollerith's system could now be adjusted to suit various industrial and commercial enterprises.

Machines were custom-built to suit the needs of the user. Until 1906, the electrical connections needed to correlate data required hand-soldering to process new combinations of data, a time-consuming process. Hollerith automated the changes by providing a plug board, permitting easy switching of the wires, effectively creating a process of physical programming that prefigured electronic programming of computers.

IMPACT

Hollerith's tabulator made it possible for the U.S. Census to complete future decennial head counts in time for the constitutionally mandated reapportionment of the House of Representatives. Counting by hand could not have kept up with the rapidly increasing American population. As Hollerith improved his machines, it became possible not only to count but also to correlate data. One could now easily determine how many families were headed by two parents, how many children were in each family, and what language they spoke, or any other combination of desired characteristics. The superintendent of the 1890 census boasted that for the first time it had been possible to produce the most complicated tables as easily as the simplest, providing invaluable information for governments, social scientists, and industry.

The improved machines proved particularly useful to managers of the increasingly large and complicated American business enterprises. After the New York Central Railroad used tabulators in 1896 to keep track of freight shipments, railway companies discovered even more ways the machines helped in running day-to-day operations and providing easily retrievable business information. Hollerith's cost-accounting machines transformed the fields of commercial bookkeeping and industrial accounting. Department stores depended upon the machines for sales analysis. Insurance companies used hundreds of thousands of cards to keep track of their policies. Hollerith's machines expanded female employment opportunities, since the devices were as easy to use as a typewriter.

For the first time, business as well as government could process massive amounts of information efficiently, economically, and in time to be of use. Until replaced by computers, for which Hollerith's tabulators were a significant forerunner, his machines would be indispensable for data processing.

—Milton Berman

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See also: Charles Babbage; John Presper Eckert; Ted Hoff; Jack St. Clair Kilby; John William Mauchly; Konrad Zuse.

NICK HOLONYAK, JR.

American electrical engineer and physicist

Holonyak invented the first practical light-emitting diode, the first visible-spectrum semiconductor laser, and the household light-dimmer switch. In 2004, he coinvented the transistor laser.

Born: November 3, 1928; Zeigler, Illinois
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Light-emitting diode (LED); visible-spectrum semiconductor laser; light-dimmer switch; transistor laser

EARLY LIFE

Growing up in the southern Illinois coal mining community, Nick Holonyak (HOHL-uhn-yak), Jr., was drawn naturally to anything mechanical or electrical. His parents, Nick (Nickolai) Holonyak and Anna Rosoha, were immigrants from the Carpathian Mountain region of Eastern Europe. The junior Holonyak was born in 1928 in Zeigler, Illinois. Holonyak and his younger sister, Evelyn, were the first in their family to attend school. In 1936, the family moved to Glen Carbon, Illinois.

Because everyone in Holonyak's community made,

LIGHT-EMITTING AND LASER DIODES

Nick Holonyak, Jr.'s February, 2001, *Scientific American* article, "In Pursuit of the Ultimate Lamp," describes light-emitting diodes (LEDs) and laser diodes. Though both diodes are made of semiconductor materials, they are designed differently to tackle different jobs. Inside the LED is a chip with layers of semiconductor material. One layer has an excess of electrons (N-type) and another layer rests on top with a dearth of electrons, or an excess of positively charged particles called "holes" (P-type). The junction of the N and P layers is the "active" layer. Applying a voltage drives the electrons and holes into the active layer where they meet. As they join, they emit photons, the basic units of light. The atomic structures of the active layer and adjoining materials on each side determine the number of photons produced and their wavelengths (the wavelengths of light determine the colors). In LEDs, the semiconductor material used is a mixture of group III and group V elements of the periodic table.

In laser diodes, the semiconductor material rests between what is essentially a pair of mirrors in the region called the "resonator cavity." When electricity goes through the semiconductor, it gives off photons, which bounce around inside the cavity, exciting nearby electron-hole pairs to release more photons at the same wavelength. The light increases continuously in intensity, with the photons moving together as they oscillate between the two mirrors. If one mirror allows just a bit of light to escape, then some of the photons exit. All at the same wavelength and in phase, these escaping and "coherent" photons produce an extremely narrow column of pure, bright light at a single wavelength. This well-defined beam is a laser, and with proper optics, it can do delicate work such as reading the fine pits on a compact disc or scanning bar codes. The word "laser" is an acronym for "light amplification by stimulated emission of radiation."

In contrast, the light emitted from LEDs is "incoherent." That is, the photons are more widely scattered and are composed of a spread of wavelengths from one area of the spectrum. While the photons an LED produces are not all the same wavelength, they are close enough to be perceived by the eye as being the same color.

Holonyak's first III-V alloy PN junction LED is the prototype for all the high-brightness LEDs made today. Through decades of improving crystal manufacturing techniques, tailoring the properties of the semiconducting layers, and even reshaping the chip itself, researchers have developed bright-light LEDs in every color of the rainbow, including white. In addition to the first red indicator lights, LEDs can be seen everywhere, lighting up traffic lights and signals, message and display boards, automotive brake and headlights, laptop displays, and interior and outdoor spaces, to name a few. During the 2008 Beijing Olympics opening ceremony, the world witnessed a thirteen-hundred-square-meter LED scroll display on the stadium floor upon which performers walked, danced, and drove. The Beijing Water Cube housed 440,000 LEDs embedded throughout its structure.

repaired, and reused whatever they needed, Holonyak became handy with tools and fixing equipment. His godfather's Ford Model T provided a lesson in spark coils and ignition. Holonyak dabbled in making radios with crystal sets, oatmeal boxes, and tuning wires. He turned his dad's carbide lamps into soldering irons. By the time he entered Edwardsville High School, Holonyak was ripe to learn the physics of how and why things worked. His teachers gave him a solid grounding in mathematics.

From 1944 through 1946, Holonyak worked on the Illinois Central Railroad during the summer and on school holidays. Ten hours a day of backbreaking manual labor convinced him that going to college would better enable him to contribute to society. By the time he completed high school, World War II had ended. The University of Illinois at Urbana-Champaign (UIUC) was impacted with soldiers returning from combat. Fortunately, Holonyak was accepted to the university's extension program, for which he paid with his railroad earnings.

He entered UIUC as a sophomore in 1947, a remarkable year in electronics history. Physicist John Bardeen and his colleague Walter H. Brattain, working at Bell Telephone Laboratories (Bell Labs) in New Jersey, had invented the point-contact transistor using the semiconductor germanium. Transistors amplify or switch electrical signals and, together with other semiconductor-based devices, are the fundamental building blocks of solid-state electronics.

LIFE'S WORK

By 1951, Holonyak had earned both his bachelor's and master's degrees in electrical engineering and was working toward his doctorate. That same year, Bardeen left Bell Labs and became professor of electrical engineering and of physics at UIUC. Holonyak took Bardeen's atomic physics and semiconductor courses and found him fascinating. In 1952, Holonyak transferred from a lab working on microwave tube problems to Bardeen's semiconductor lab, becoming Bardeen's first graduate student. In addition to forging what would be a lifelong friendship with Bardeen, Holonyak learned as much as he could about the nature of semiconductors, growing crystals, and testing their conductivity. Holonyak felt at home there: Everything in Bardeen's new lab had to be built from scratch, including the benches. An added benefit was learning from other world-renowned scientists who visited Bardeen's lab.

In 1954, Holonyak earned his doctorate in electrical engineering and took a job with Bell Labs in New Jersey. Bell Labs was researching new low-voltage, low-current technology to replace the vacuum tubes and relays in telephone switching systems. Holonyak's supervisor, John L. Moll, was convinced that silicon was a superior elemental semiconductor material to germanium and that it would work better for switching devices. Holonyak was put to work developing silicon-diffused transistors and silicon thyristors. Many of what would become integrated circuit (IC) manufacturing processes, including oxide masking, were developed during this time by Holonyak and other Bell Labs researchers. Holonyak credits Moll with being the first to recognize and promote silicon's future role in electronics.

In 1955, Holonyak married Katherine Jerger, a nursing educator. After a year at Bell Labs, Holonyak joined the U.S. Army Signal Corps, which stationed him in Yokohama, Japan, and worked on classified projects. Upon his discharge in 1957, he moved to the electronic devices lab at General Electric Company (GE) in Syracuse, New York. While there, Holonyak's work on silicon thyristors led him to invent the symmetrical switch, the fundamental silicon device used in household light-dimmer switches.

By 1960, GE scientists were experimenting with gallium arsenide, a III-V semiconductor compound alloy (III and V referring to columns of the periodic table). In July, 1962, Massachusetts Institute of Technology (MIT) scientists reported that their gallium arsenide diode was converting electric current into infrared light. Holonyak wanted to work with visible light and had an idea that a gallium arsenide phosphide (GaAsP) diode could emit red light. He and his technician went to work on making this new crystal from scratch. By October, 1962, Holonyak had succeeded in making the first visible-spectrum diode laser. This time, Bardeen, Holonyak's mentor and by then a Nobel laureate, went to Holonyak's GE lab to see it.

Not only did Holonyak's GaAsP diode produce red laser light, but it also (after more and more phosphorus was added to the gallium arsenide) stopped lasing yet remained a useful light source. Holonyak had invented the red light-emitting diode (LED), the first operating alloy device. He quickly devised a proof that the LED was an "ultimate lamp."

In 1963 and earlier, Bardeen asked Holonyak to consider returning to UIUC as a faculty member. Holonyak accepted the position, as he enjoyed both teaching and being at the forefront of invention. Through numerous discoveries and advancements in laser technology, Holonyak and his UIUC students have continued inventing better lasers. Their work has made lasers practical for myriad applications, including compact disc (CD) and digital video disc (DVD) players, high-frequency cell phone circuits, fiber-optic communications, medical diagnosis, surgery, copy machines, laser printers, and laser television and projectors. In 1993, Holonyak became the John Bardeen Endowed Chair Professor of Electrical and Computer Engineering and Physics, a fitting tribute to both gentlemen. Holonyak has kept all three inventions—the symmetrical switch, first visible laser, and first LED—in a box he calls "the coffin" inside his UIUC office desk.

While having a coffee break in 2003, Holonyak asked his former student and UIUC colleague Milton Feng (inventor of the world's faster transistor) if he had seen any light coming out of his high-speed heterojunction bipolar transistor. Feng told Holonyak he had not, but after a few months and a different detector, Feng did see infrared light shooting out in all directions from his transistor. After modifying the transistor's structure to favor light emission and to intensify it into a laser beam, in 2004 Feng, Holonyak, and their research team demonstrated the transistor laser. At once a new form of transistor and a new form of laser, it marked the first time a single device had taken an electrical input and simultaneously output both an electrical signal and a coherent optical signal. Holonyak told several reporters that Bardeen (1908-1991) would have a big smile to see how far his and Brattain's invention had come in fifty-eight years.

IMPACT

Holonyak's LED has sparked revolutionary changes in the traditional lighting industry and has become the basis of a global optoelectronics industry worth billions of dollars. In addition, the transistor laser may prove to be one of the most important inventions since the original transistor. Processing information at the speed of light, the transistor laser could lead to faster signal processing, larger capacity seamless communications, and higher performing electrical and optical ICs. "Like the fundamental work that went into creating the point-contact transistor, then the junction transistor, and eventually the LED and the laser—and ultimately led to the booming semiconductor industry—our work is just at the beginning of what could be a new era in computing and communications," said Holonyak and Feng in their February, 2006, *IEEE Spectrum* article, "The Transistor Laser."

The LED is proving to be the best-qualified device to replace Thomas Alva Edison's light bulb. Energy and lighting standards are requiring more efficient light bulbs. The very definition of "green" energy, the LED emits more intense light at much lower power and for decades longer than the incandescent bulb, and it does not contain the harmful mercury found in compact fluorescent bulbs.

Holonyak's legacy is rooted in his more than sixty postdoctorate students who have become entrepreneurs, professors, business leaders, and inventors. Many of Holonyak's former students shared his lessons at Holonyak's October, 2008, eightieth birthday symposium at UIUC's Beckman Institute: Tackle the problems within your reach with hard work and collaboration; build and test, do not just model, your ideas; and even a small group can take on a big problem and really have an impact around the world. Holonyak holds forty-one patents and is the recipient of numerous awards, including the Japan Prize (1995), Russia's Global Energy Prize (2003), Lemelson-MIT Prize (2004), and both the National Medal of Science (1990) and National Medal of Technology and Innovation (2002). He is a 2008 inductee to the National Inventors Hall of Fame.

—*Sheri P. Woodburn*

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See also: John Bardeen; Walter H. Brattain; James Fergason; Gordon Gould; Shuji Nakamura; Charles Hard Townes.

ROBERT HOOKE

English physicist

Hooke did significant research in most areas of seventeenth century science, including collaborating with Robert Boyle on inventing the first air pump, building a microscope with which he made important discoveries, inventing the universal joint, and investigating planetary motion. He was one of Sir Christopher Wren's two assistants in rebuilding fifty-one city churches after the Great Fire of London in 1666.

Born: July 18, 1635; Freshwater, Isle of Wight, England
Died: March 3, 1703; London, England
Primary fields: Architecture; navigation; physics
Primary inventions: Air pump; spiral spring balance watch; universal joint

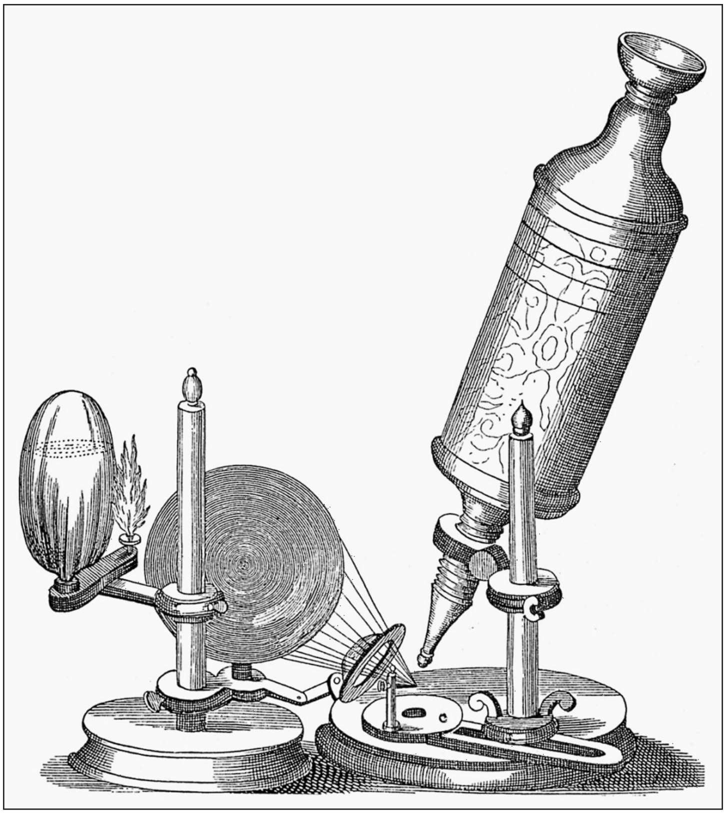
EARLY LIFE

Robert Hooke was born on July 18, 1635, in the village of Freshwater on the Isle of Wight, where his father, John Hooke, was the curate of All Saints', the parish church. His mother, Cecilie, née Gyles, was John Hooke's second wife. Robert had two older sisters, Anne and Katherine, and an older brother, John, who left home to become a grocer in Newport. Robert was a weak child, raised on a mild diet and educated at home. He soon evinced extraordinary talents, especially in mechanical pursuits, and imitated the work of the local craftsmen, while cultivating a lifelong interest in clocks and navigation. His skill with the pen and pencil facilitated his later work in microscopy and mechanics, as well as his work as an architect and surveyor.

Hooke's father died in 1648, and he took his £50 inheritance and braved a new life in busy London. He went first to the London suburb of Westminster, where he had planned on assuming an apprenticeship with the Dutch portraitist Peter Lely, but he quickly scrapped this plan and instead enrolled at Westminster School. The headmaster at Westminster, Dr. Richard Busby, was a stern taskmaster, and sixteen of his students became bishops. Hooke stayed in Busby's house from 1649 to 1653, learned to play the organ, studied Euclid, and mastered Latin and Greek. It was at this time that he developed his intense interest in flying. When he was sixteen years old, he became afflicted with a twisted back, a condition that Stephen Inwood speculates may have been a deformity identified in 1921 as Scheuermann's kyphosis, in which the vertebrae become misaligned. Unfortunately, Hooke's forward stoop became worse as he grew older, as is common with kyphosis sufferers.

LIFE'S WORK

In 1653, Hooke entered Christ Church, Oxford, as a servitor, a student who earned his keep by working for a rich student. In 1656 or 1657, he was employed by the wealthy scientist Robert Boyle and lived in Boyle's home until at least 1662. Unlike many scientists of his day, Boyle was devoted to the experimental method, and at his urging Hooke devised an air pump in 1658 or 1659. This important invention enabled Boyle to formulate



Robert Hooke's microscope, from a line engraving based on the illustration in his Micrographia *(1665).* (The Granger Collection, New York)

Boyle's law: The volume of a gas, the temperature remaining constant, varies inversely with the pressure sustained by it. Hooke's successful association with Boyle led to his appointment in 1662 as a Royal Society curator of experiments, and in 1664 he moved into rooms at Gresham College in London, where he was installed in 1665 as Gresham Professor of Geometry and lived until his death.

Spiral Spring Balance Watch

Robert Hooke's famous principle of Hooke's law grew out of his work to build a reliable timepiece that would enable sailors to determine longitude at sea. If a ship carried an accurate clock that was set to the time of the port from which it had left, then since the Sun swept across 15° in an hour, when the Sun stood directly overhead at high noon the vessel's longitude could be calculated by simple arithmetic. If, for instance, the ship's clock read 4:00 P.M., its longitude would be 4 × 15° west of its embarkation point. This theory, however, depended on a reliable timepiece, and the great challenge was thus to develop a clock that would still keep accurate time while being tossed around in a rough ocean. Several trials of conventional pendulum clocks were conducted at sea in the early 1660's, but Hooke scorned them as inconsistent.

A breakthrough came in 1674 when Christiaan Huygens announced that he had devised a spiral spring balance, an innovation that would be the basis of Hooke's law. The physical principle was that the energy tensioning a balance spring would equal the energy released by the spring, creating an isochronal action as trustworthy as the pendulum and not dependent on gravity. Huygen's announcement came in two letters read to the Royal Society by Henry Oldenburg, and it spurred Hooke to declare that he had invented the spring-regulated watch in 1658, but his only evidence was a reference to it in the Royal Society register book for 1666. When Hooke learned in 1675 that Huygens had offered Oldenburg the patent on his spring watch, he accused Oldenburg of profiteering from his position as secretary of the Royal Society and of revealing the secret of Hooke's watch to Huygens. Hooke also began collaborating with the skilled instrument maker Thomas Tompion in building a spring watch of his own that would outperform any timepiece that Huygens could produce.

Tompion was a superb craftsman, and by late 1675 he and Hooke had a watch with a spiral balance spring to present to King Charles II boasting the engraved inscription "Robert Hook inven. 1658. T. Tompion fecit 1675." Until 2006, there had been no way of confirming Hooke's claim, but then an auctioneer examining the contents of a home in Hampshire found over five hundred yellowing manuscript pages in a cupboard. This remarkable find proved to be Hooke's notes of the Royal Society meetings from 1661 to 1682, a trove that completed the society's records. In one passage, Hooke reports that in the draft minutes for June 23, 1670, Oldenburg had written: "The curator [Hooke] produced a pocketwatch of a new contrivance devized by himself, which he affirmed should goe as equally as a pendulum, and without stopping, and might be made to goe for 8 days." Sixty years after Hooke's death, the work of the inventor John Harrison led to a chronometer that would give a ship's exact position at sea, an accomplishment that built upon Hooke's spiral spring-governed balance wheel and escapement.

Hooke's early research for the Royal Society included studies in navigation, working on a depth sounder, fixing the freezing point of water at zero degrees, and making a wheel barometer. He dissected a living dog to study its lungs, discovered a dark spot on Jupiter, and described in *Micrographia* (1665) the features he discerned on the Moon. Hooke revealed wondrous discoveries in *Micrographia*, including a patch of blue mold on a leather book, an eruption of blight on a rose leaf, and the tiny compartments in cork for which Hooke coined the word "cells." The book was an astonishing compendium of five years of inspired work, with disquisitions on light, fossils, animal behavior, lunar craters, and a multitude of other topics. Samuel Pepys, the diarist, called *Micrographia* "the most ingenious book that ever I read in my life." Hooke's observations of the development and birth of gnats in a jar of rainwater prompted him to question "whether all those things that we suppose to be bred from corruption and putrifiction, may not be rationally suppos'd to have their origination as natural as these Gnats. . . ."

Hooke was the first to posit the correct role of gravity in creating planetary motion when he read a paper to the Royal Society in May, 1666, "On the Inflection of a Direct Motion into a Curve by a Supervening Attractive Principle." This paper evolved in four years into a theory of universal gravitation, proposing that all bodies, not just the Sun, exerted attraction over bodies orbiting around it. Second, all bodies put into motion would remain in a straight line unless some force deflected them. Finally, the attracting power was stronger near the center of the attracting body and weakened at longer distances. Also in 1666, Hooke calculated the rotation of Mars on its axis within thirty-seven minutes of the time accepted today, developed a clock based on a conical pendulum, and invented a quadrant featuring a screw-controlled adjustment and a reflecting mirror, an advance over previous quadrants but fated to be neglected until John Hadley came up with a similar instrument in 1731.

The fire that devastated London in 1666 changed Hooke's career, as he was appointed along with two others to the city's Rebuilding Commission and named city surveyor. In the 1670's, he was kept busy with architectural work. He was appointed in 1670 as one of Christopher Wren's assistants in rebuilding fifty-one city churches, and from 1671 to 1679 he was employed in designing and building a new college for the Royal College of Physicians. In this same decade, Hooke worked on the Monument to the Great Fire of London for five years and on the Bethlem Royal Hospital and the grand Montagu House in Bloomsbury, while also struggling to devise a better calculating machine than Gottfried Wilhelm Leibniz's, exhibiting the first practical Gregorian telescope (named for James Gregory), helping design the Greenwich Observatory, and collaborating with Thomas Tompion in the creation of a good spring watch. The spiral spring watch, in fact, was to become the subject of controversy until 2006.

Hooke continued to investigate subjects as diverse as lenses, the mechanical nature of memory, cannabis, fossils, and the changing shape of the Earth. His last recorded contribution to a Royal Society meeting came in June, 1702, nine months before his death apparently of heart and circulatory ailments in March, 1703. He enjoyed a long career in which he left his mark upon most of the branches of natural philosophy current in his day.

IMPACT

"*Micrographia*, therefore, became one of the formative books of the modern world, and like all influential pieces of writing, was capable of triggering responses on many different levels of understanding." That is Allan Chapman's judgment of Hooke's great book, and Stephen Inwood is equally flattering, noting that extracts were used in many scientific works for the next 150 years. Hooke had many inventions and advancements to his credit—the universal joint, for instance, and the spiral spring watch—but his main legacy was his devotion to the experimental method. He demonstrated that this approach to science (or natural philosophy as it was known) could achieve great insights into the workings of nature and enable the mastery of nature. Many of Hooke's experiments may have seemed laughable to Jonathan Swift in his satire on the Royal Academy in *Gulliver's Travels* (1726), and to King Charles II, who laughed at the comical Hooke and his contraptions. Most insulting was Thomas Shadwell's mean-spirited play *The Virtuoso* (pb. 1676), in which Hooke is satirized as Sir Nicholas Gimcrack.

Nobody sneers at Hooke today. Boyle's law and Hooke's law are firmly embedded in the discipline of physics, Hooke's speculations on fossils and the history of the Earth are no longer dismissed as outlandish, and his architectural successes have long been admired, perhaps none more so than the great monument to the fire. For several decades, Hooke bustled about on multiple projects—quadrants, telescopes, microscopes, watches, universal joints, and sketching the eye of a fly. Allan Chapman was certainly right to dub him "England's Leonardo."

—*Frank Day*

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ticle quotes Michael Hunter of Birkbeck College on the discovery: "It is an extraordinary discovery, filling a gap in the documentation of the early Royal Society and including details of discussions at various meetings that have hitherto been unknown."

See also: Roger Bacon; Giovanni Branca; James Gregory; Otto von Guericke; John Harrison; Christiaan Huygens; Zacharias Janssen; Thomas Jefferson; Antoni van Leeuwenhoek; Thomas Newcomen; Sir Isaac Newton; John Augustus Roebling.

ERNA SCHNEIDER HOOVER

American computer scientist

A pioneer in computer technology and one of the first women in the field, Hoover revolutionized telecommunications by designing a computerized switching system able to process an unprecedented volume of incoming calls.

Born: June 19, 1926; Irvington, New Jersey
Also known as: Erna Schneider (birth name)
Primary fields: Communications; computer science; electronics and electrical engineering
Primary invention: Electronic switching system

EARLY LIFE

Erna Schneider was born on June 19, 1926, in Irvington, a metropolitan area in industrial northeastern New Jersey. One of three children, Erna grew up in a happy and supportive home—her father was a dentist and her mother a teacher in the South Orange public school system that Erna attended. Early on, Erna was enthralled by science, in part because of her father's influence and in part because of her love of the outdoors (particularly the nearby Adirondack Mountains), which gave her an appreciation for the subtle design of ecosystems. Two events in particular shaped the direction of Erna's education into the sciences: the death of her younger brother at age five from poliomyelitis (then a terrifying illness without a cure) and her subsequent introduction to the work of Marie Curie through a biography she received from a teacher. That biography impressed young Erna by revealing how science solved problems, giving her a practical rather than theoretical sense of science. In addition, the example of Madame Curie encouraged Erna to pursue a career that at the time was dominated by men.

Gifted in the classroom, Erna completed her B.A., graduating Phi Beta Kappa in 1948 from Wellesley College, a prestigious women's college in Massachusetts. Despite her love of science, her degree was in classical and medieval philosophy and history; she was encouraged to pursue university teaching as a career appropriate to her gender. Within three years, she had completed a doctorate at Yale University in philosophy and foundations of mathematics. For the next two years, she taught logic and philosophy at Swarthmore College outside Philadelphia. However, because she was married (in 1953, she had married physicist Charles Wilson Hoover), she would not be offered a tenure-track appointment. In 1954, at her husband's encouragement, she applied for a senior research position at Bell Laboratories, a cutting-edge research facility in electronics headquartered in Murray Hill, New Jersey. Within a year, because of her grounding in symbolic logic (key to developing circuit designs), she was assigned to work in Bell Labs' accelerated training program in computer science.

LIFE'S WORK

Bell Labs was at the forefront of the postwar technology boom made possible by its introduction of transistors, which were used not only in the development of the first-generation computers but also in everyday household items, from toasters to radios. Given Bell Labs' prominence, it was swamped daily with hundreds of phone calls that had to be handled by its hard-wired, mechanical switching equipment. The demand on the group's system was immense, and the system regularly froze, overwhelmed by the volume of calls that had to be processed. The system's switches first counted the digits dialed, then determined where to direct the call, and finally connected the parties. This methodical, time-consuming endeavor was designed to handle perhaps one hundred calls per workday. The results—dropped calls, busy signals, misrouted calls—created havoc. These problems were hardly Bell's alone; they were significantly multiplied in public telephone networks. In 1954, Bell organized a division research team to look into an electronic switching system (ESS) that would use cutting-edge transistor technology to design the architecture of a system able to handle a high volume of incoming phone calls.

Hoover served on the project's initial work, in part because of her grounding in logic. Drawing on that discipline with its assumptions of orderly processes and her own profound admiration for the discipline and order of nature, Hoover was determined to create a system capable of directing the incoming data. When in 1957 she was compelled to take maternity leave (to give birth to her second child), she initially resisted. Ironically, however, it was while she was in the hospital recovering from that birth that—inspired by watching the triage practices of orderlies and nurses in the hectic delivery room facility where cases were routinely managed by the staff by assigning priority to critical cases and holding off attention to less pressing ones—Hoover first sketched (literally, on hospital napkins) what would become the basic design of a working ESS. It was, Hoover would recall later, a simple idea: prioritize the thousands of incoming calls, monitor the frequency of incoming calls throughout a standard workday, and adjust the acceptance rate according to high-volume times, thus distributing the calls into a kind of pecking order that would maintain the system without the threat of breakdowns.

Returning to Bell, Hoover spearheaded the project that gathered the initial data, tracked incoming call patterns, and developed reliable traffic reports that enabled Hoover, over the next five years, to design the Stored Program Control, the software with the memory sufficient to engineer the phone system. It was a massive undertaking. The project alone received more than $500 million in research funding from Bell. With computer-assisted technology (transistor circuits and memory-stored control programs), Hoover's ESS would be able to control the distribution of thousands of calls per second by analyzing the importance of the calls (based on exchange numbers), prioritizing them (research departments, for instance, ahead of clerical), and maintaining control of the system with a significant reduction in the number of staff persons assigned to the task. Given the revolutionary design and its potential impact in electronic telecommunications, Bell decided in 1967 to apply for a patent (while Hoover was again on maternity leave for her third, and last, daughter).

Hoover's Feedback Control Monitor for Stored Program Data Processing System was awarded a patent on November 23, 1971, among the earliest patents awarded to computer software. Hoover, by then promoted to research supervisor (the first woman so promoted), had

The Electronic Switching System

Erna Schneider Hoover's patent application for the electronic switching system (ESS) specifically related to stored program data processing machines that routinely routed incoming phone calls. Specifically, her interest was in developing a software program that would assist the processing under conditions of high stress—periods of high-load conditions in which existing systems tended to break down. To monitor traffic flow, Hoover's software program began by determining a base-level functioning flow—that is, a measure of standard occupancy under which the program could maintain sufficient exercise over calls without malfunction. The system used a particular class of work—both input and output—that the processor performed routinely and repetitively under normal conditions and measured the time interval for performing those tasks. That indication of occupancy was in turn used to control the rate at which new work, or new calls, would be taken into the system for processing. Of course, the process of looping back and assessing volume was done at great speeds. Essentially, Hoover's software provided a continual overview of traffic flow, monitoring the frequency of incoming calls during the day and then adjusting the acceptance rate when the system entries exceeded the predetermined limit. The system would in turn temporarily relegate the volume of calls that would stress the system into breakdown into "hoppers," or areas of buffered and protected memory within the system designed specifically for such short-term storage.

From that point, the executive control, the brains of the data processing system, determined the order in which the overload data would be fed back into the system, dividing the data into several classes according to urgency of the tasks. The idea was to route pressing calls first and then move on to less urgent concerns such as billing or ordering. That switching system maintained control of the data flow during the period of high input until the system managed itself back to predetermined functioning time. By measuring machine occupancy continually and in turn controlling the number of new numbers permitted into the network, the software program stayed current and actually reacted to unfolding conditions. The executive control would continuously revisit the system until either the hoppers were emptied or the quota for a single visit was reached. Thus, the system monitored itself, maintaining an even distribution of incoming calls without appreciable delays or dropped calls, preventing the surge in data that regularly compromised manual systems. Hoover's system architecture became the foundation for all computer routing programs for private and public telephone systems, thus ushering in the era of telecommunications.

been reassigned to work on the high-profile, top secret research project investigating radar control programs that would help intercept incoming intercontinental ballistic missiles. Given that Hoover's work was done during some of the most difficult and tense years of the Cold War, she has been credited with creating the necessary bargaining chip for a succession of presidents to negotiate significant weapons treaties. In 1978, in recognition of her achievements, Hoover was promoted to technical department head (again, the first woman to have that title at Bell Labs).

She retired in 1987 to Summit, New Jersey, where, along with her husband, she lived an active retirement enjoying the outdoors. Although her design basically created telecommunications, she lived quietly; she would tell whatever reporters came to her home that her idea was just common sense. In February, 2008, Hoover received long overdue international recognition when the National Inventors Hall of Fame named her among that year's class of inductees.

IMPACT

In the 1950's, telephoning involved actually talking to an operator who would manually direct a call by plugging a wire into a switchboard. As phone communications exponentially increased during the postwar business boom (most dramatically after transatlantic telephone cables were introduced in 1956), the problem of overloaded, jammed systems became evident. Undeniably, Erna Hoover's insight into how electronics could be applied to adjust the acceptance rate of incoming phone calls revolutionized postwar telecommunications. After Bell Labs introduced the first computer storage system (initially into its own phoning system), within two years the system program and its software were in commercial service for public networks all over the country.

The growth of the system innovation that Hoover first described is difficult to fathom—but within twenty years, just under two thousand such switching systems were managing more than fifty million subscriber lines. Although successive designs of the system have built upon Hoover's initial idea, all business and private phoning systems directly descend from Hoover's insight. Indeed the basic logic of Hoover's design has provided the system architecture for Internet managing of millions of e-mail messages sent every minute.

Far more important than the impact her innovative design had on the evolution of mass communications is Hoover's stature in the social and cultural history of postwar America as a pioneering woman in a field that was the province of men at that time. Her example in how, despite the glass ceiling, a woman can succeed—both in the workplace and at home—by dint of ingenuity and dedication has had a powerful impact on attracting women to the fields of computer science and electrical engineering.

—*Joseph Dewey*

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Hatch, Sybil E. *Changing Our World: True Stories of Women Engineers*. Reston, Va.: American Society of Civil Engineers Press, 2006. Technical investigations into the contributions of dozens of twentieth century female engineers (Hoover, although not an engineer by training, is included), with analysis of biases they encountered. Detailed illustrations.

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See also: Vinton Gray Cerf; Martin Cooper; Grace Murray Hopper; Bob Kahn.

GRACE MURRAY HOPPER

American mathematician and computer scientist

Hopper was a U.S. naval officer who eventually rose to the rank of rear admiral. She is best known for her work on the development of COBOL as a computer programming language. She also created a large variety of computer software that was innovative in terms of the problems addressed.

Born: December 9, 1906; New York, New York
Died: January 1, 1992; Arlington, Virginia
Also known as: Grace Brewster Murray (birth name)
Primary fields: Computer science; electronics and electrical engineering
Primary invention: COBOL programming language

EARLY LIFE

Grace Brewster Murray was the eldest of three children born to Walter Fletcher Murray, an insurance broker, and Mary Campbell Van Horne Murray of New York City. Her family was fairly well off, and she spent her childhood summers at the family cottage on Lake Wentworth in Wolfeboro, New Hampshire. Her father encouraged her not to follow the traditional roles that women typically followed at that time. From her surveyor grandfather, John Van Horne, she learned about angles and curves, which may have led to her interest in a mathematics career, although she credited her mother's interest in the subject as being the main influence. Murray received her bachelor's degree in mathematics and physics from Vassar College in 1928, graduating Phi Beta Kappa, and earned a master's degree in mathematics from Yale University in 1930. In 1934, she became the first woman to receive a doctorate in mathematics from Yale. Her dissertation was titled "New Types of Irreducibility Criteria" and was written under the tutelage of famed algebraist Øystein Ore.

Murray married Vincent Foster Hopper in 1930, when she was twenty-three years old. Hopper was an honors graduate of Princeton University and later earned a doctorate in literature at Columbia University. The couple separated in the early 1940's and were divorced in 1945. He died shortly afterward in the final days of World War II. They had no children.

Grace Hopper served as a faculty member at Vassar College from 1931 to 1943, at which time she joined the U.S. Navy's Bureau of Ordnance at Harvard University as a mathematical officer, working under Howard Aiken. Her great-grandfather Alexander Russell had been a rear admiral, and she had always been interested in the Navy. At the age of thirty-seven, she was initially considered too old for the Navy, but her specialty in mathematics was crucial, and the Navy relented and accepted her. There was also a problem with her weight: At 105 pounds, she was sixteen pounds underweight for her height of five feet, six inches. However, she was granted a waiver. Because of her educational background, she was sent to Midshipman's School and graduated at the top of her class in 1944, becoming a lieutenant (junior grade).

Her first job was as one of the initial programmers on the Navy's Mark I—the first large-scale digital computer. The Mark I was fifty-one feet long, eight feet tall, and eight feet wide and was considered a marvel of modern science. It contained five hundred miles of electrical wire and over 750,000 parts. The computer was used to calculate aiming angles for guns in various types of

Grace Murray Hopper. (Naval Historical Center) weather to determine the flight path of artillery shells. Hopper and her assistants had to keep the computer running twenty-four hours a day during the war. In 1946, much of her wartime knowledge was incorporated into a book that she coauthored with James Conant—*A Manual of Operation for the Automatic Sequence Controlled Calculator*.

LIFE'S WORK

Following the war, Hopper was released from active duty, but she remained in the Naval Reserve. She joined the Harvard faculty at the Computation Laboratory, where she continued her work on the Mark II and Mark III. From 1949 to 1967, she worked as a mathematician for Eckert-Mauchly Computer Corporation, which was later acquired by Sperry Rand Corporation. From 1967 through September of 1986, she was on active duty with the Navy. She was promoted to commodore in 1983 at the age of seventy-six. When she retired from the Navy as a rear admiral in 1986, Hopper was the oldest-serving officer at that time and the first female admiral in the history of the Navy. Late in her career, at the age of eighty, she joined Digital Equipment Corporation, where she worked from 1986 to 1988.

At Sperry Rand, Hopper had the opportunity to work on the Universal Automatic Computer, better known as UNIVAC, which operated one thousand times faster than the Navy's old Mark I. The UNIVAC was the first commercial electronic computer. It used vacuum tubes instead of the electromechanical relay switches of the Mark calculating machines. In 1952, she invented the compiler, an intermediate program that translated English-language instructions into computer language. She also was the first to use now standard computer tools such as subroutines, formula translation, code optimization, and symbolic manipulation.

Hopper is best known for creating the computer programming language known as Common Business Oriented Language (COBOL). COBOL was the first language that allowed a programmer to talk to a computer with words rather than with numbers. Before COBOL, computer programs were written either in assembly code or some type of machine code. Hopper felt that programmers should be able to communicate with computers in English.

Hopper is also known for popularizing the term "bug" to describe a computer glitch. Today, correcting problems in computer software is known as "debugging." Hopper used the term "bug" when she traced an error in the Mark II to a real bug—a moth trapped in a relay switch. The moth was removed and taped to a computer log book. Initially, "bug" referred to problems with hardware, but in the 1950's Hopper extended the meaning of "debug" to include fixing software programming errors.

Most of Hopper's inventions dealt with software. Her innovative ideas included computer programs to track the life cycle of crop-eating locusts, a weather computer, software to manage water reserves, and programs to track wave motions at the bottom of the ocean. In 1966, she was promoted to commander in the Naval Reserve, but she had reached the legal limit of twenty years' service and was forced to retire. However, within six months, the Navy decided that it needed her back to work

COBOL: A COMPUTER PROGRAMMING LANGUAGE

Grace Murray Hopper is best known for creating the Common Business Oriented Language (COBOL), a programming language that permitted programmers to communicate with computers by means of the English language rather than through numbers. Hopper attributed the idea for COBOL to her difficulty in balancing her checkbook. Early computers were programmed using a machine code that used numbers. Hopper had learned to add, subtract, multiply, and divide using a numbering system to the base eight, known as the octal system, which used digits 0 through 7. Unfortunately, Hopper became so adept at using the base-eight system that she inadvertently used it when she added and subtracted in her checkbook. Thus, her checkbook did not balance because she was not using the decimal system.

To alleviate the problem of programmers having to use the octal system, she suggested that the Universal Automatic Computer (UNIVAC), the first commercial electronic computer, be programmed to understand English commands. Initially ridiculed by other programmers, Hopper developed the B-0 compiler, later known as FLOW-MATIC, which by 1956 had enabled the UNIVAC to understand twenty English-like phrases. By 1959, this compiler had led to the first standardized universal computer language—COBOL. COBOL was used to retrieve accounting, billing, and payroll data, and the program was easy to use. Hopper then created the manuals to enable others to learn COBOL and to program their own computers. Nicknamed the "Grandmother of COBOL" and "Amazing Grace," Hopper was recalled to active duty in the Navy in 1967 to continue her work on COBOL.

on COBOL. In 1967, at the age of sixty, she returned to active duty. Her new job was to combine versions of COBOL into a USA Standard COBOL.

In her later years, Hopper was a venerable figure, nicknamed "Amazing Grace" for her accomplishments and her ability to motivate audiences. During her career, she was granted more than thirty-seven honorary degrees, including ones from the University of Pennsylvania, Long Island University, and the Newark College of Engineering. Other honors included her selection for the 1969 "man of the year" award (she was the initial recipient of this award) from the Data Processing Management Association. In 1991, she was awarded the nation's first National Medal of Technology by President George H. W. Bush. In 1994, more than two years after her death, she was inducted into the National Women's Hall of Fame. The Navy later launched an Aegis-guided missile destroyer named for her, the USS *Hopper*. Hopper died in 1992 and was buried in Arlington National Cemetery with full military honors.

IMPACT

Hopper's scientific achievements made her a legend in computer circles internationally. She began as one of the first programmers on the Navy's Mark I computer and progressed to become the first programmer on the first commercial computer, the UNIVAC. Her work with language compilers made computer programming easier. Following her introduction of COBOL, she published more than fifty articles on software and programming languages. Her innovative ideas for the use of computers inspired others to use computers creatively. As a naval officer, and later at Digital Equipment Corporation, she traveled throughout the world speaking to thousands about the future of computers. She was honored on television shows such as *60 Minutes* and was the subject of documentaries. Hopper's work essentially allowed noncomputer specialists to work directly with computers. Computers were made accessible to the average businessperson; in turn, businesses were more successful because of the wide availability of computer technology, which led to economic growth throughout the world.

—Dale L. Flesher

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See also: John Presper Eckert; Erna Schneider Hoover; John William Mauchly; Robert Metcalfe.

JOHN ALEXANDER HOPPS

Canadian electrical engineer

A pioneer in biomedical engineering, Hopps first experimented with applying electrical current to a failing heartbeat, laying the foundation for the artificial pacemaker that revolutionized heart care and improved the quality of life for millions of heart patients.

Born: 1919; Winnipeg, Manitoba, Canada
Died: November 24, 1998; Ottawa, Ontario, Canada
Also known as: Jack Hopps
Primary fields: Electronics and electrical engineering; medicine and medical technology
Primary invention: Artificial pacemaker

EARLY LIFE

John Alexander Hopps was born in 1919 in Winnipeg, Manitoba, in west-central Canada. Little is known about Hopps's childhood. With typical modesty, even after he had achieved considerable celebrity as the father of the artificial pacemaker, Hopps preferred to maintain a low profile and keep his personal life just that. He would speak of an idyllic childhood growing up amid the comforts of a middle-class life—Winnipeg at the time was considered one of Canada's most developed urban areas despite being in a largely agricultural province and decidedly distant from the cultural and political centers of Canada. Hopps was a precocious child and evinced early on a proclivity for mathematics. Ironically, given his eventual international reputation, Hopps never considered medicine; rather, he pursued his first love: engineering. He relished the idea of how engineering, drawing on disciplines ranging from mathematics to architecture, represented the most pragmatic application of human ingenuity. He was particularly drawn to the possibilities of electricity and how directing the energy of currents promised unlimited applications. He graduated with a degree in electrical engineering from the University of Manitoba in 1941.

Immediately, Hopps headed west, accepting that year a position at the prestigious National Research Council (NRC) in Ottawa, then (as now) among the preeminent research facilities in the world, promoting a wide range of scientific, medical, and industrial research projects. He was placed in the Radio and Electrical Engineering Division. Initially, Hopps was assigned work on the problem of improving the efficiency of the pasteurization of beer using microwave rewarming. The research environment suited Hopps: As he had little patience with theoretical work, he was drawn to the assumption that engineering was particularly suited to problem-solving and to the work of trial and error as a strategy for tackling a specific problem. He quickly distinguished himself. In 1949, his division chief recommended that Hopps transfer to Toronto's Banting Institute, where a team of medical researchers was developing pioneering applications of radio-frequency rewarming on cardiac care. Specifically, Hopps joined a research team headed by Dr. Wilfred G. Bigelow and his assistant Dr. John C. Callaghan that was investigating hypothermia, cooling the body to an extreme temperature as a technique for regulating heartbeat during experimental open-heart surgical procedures.

LIFE'S WORK

Dr. Bigelow's investigation into induced hypothermia was decidedly unconventional and widely considered risky. During late 1949, however, the research team had successfully lowered a dog's body temperature to nearly 20° Fahrenheit. The resulting slowdown in the heartbeat interrupted the normal circulation and made possible an open-chest heart procedure. Problems arose, however, when procedures were attempted to revive the heart and return it to its normative rhythm. At the time, medical science had two ways to restimulate a stopped heart: a shot of adrenalin administered directly into the heart and/or a heart massage done manually by attending physicians.

During an otherwise routine experimental procedure on a dog, its heart (perfectly healthy otherwise) unexpectedly stopped. Bigelow, more out of desperation than anything else, applied an electrical probe he happened to be holding in his hand at the time directly to the sinoatrial node. The heart, to his surprise, immediately contracted after the poke. Electrical stimulation, gently applied at measured intervals, quickly returned the dog's heartbeat to a regular rhythm without damaging any of the heart's essential muscles or nerves. The idea intrigued the team; it was at this point that the researchers sought the help of Hopps, an electrical engineer with a specific background in temperature-control experiments. They outlined their proposal: to use electrical stimulation to regulate heartbeat. This could potentially solve the problem with reviving postoperative canines and in turn clear the way for exploring the potential of open-heart surgical proce-

THE ARTIFICIAL PACEMAKER

The heart's rhythmic beat is actually an electrical impulse generated by a signal that starts in a cluster of highly developed cells of the right atrium. That signal generates the heartbeat at a specific rate, although that rate can be affected by emotional duress or short- or long-term physical impairment. With an artificial pacemaker, generated electricity is used to sustain a heartbeat when the heart's natural conduction system fails to function properly. By contemporary standards—that is, the battery-powered implantable pacemaker—John Alexander Hopps's external pacemaker can seem crude and, given the considerable pain it inflicted on its patients and its susceptibility to electrocuting the patient, even dangerous. It is best appreciated, however, for its daring, as a breakthrough step, a historic juncture when engineering and medicine cooperated to produce a device whose theoretical foundation was far more important than the device itself. It was in use for less than five years before biomedical engineering addressed the problems Hopps's design posed. Medical researchers had long theorized that electrical current could regulate the beating of a damaged heart and maintain a healthy and consistent heartbeat, but they lacked the engineering grounding to create even a prototype device.

The electrical current in Hopps's machine was created and sustained by a vacuum tube, the same technology that made possible the incandescent light bulb and later radio and then early television broadcasting. The device had a foot pedal control switch that allowed surgeons to control the flow of electricity while they would position the actual electrodes manually during open chest surgery. During postoperative care, the device monitored heart rate and instantaneously administered an electric charge should an irregularity be registered. Thus, the generator was kept near the patient and worked off a standard AC wall socket (thus exposing the unit to the danger of fire). The device was not designed to provide long-term regulation but rather to assist in maintaining a consistent heartbeat during emergency procedures or during short-term postoperative maintenance. Patients hooked up to the external pacemaker for any period of time during their postoperative recovery were limited in their mobility (only as far as the cord reached) and under considerable discomfort. Hopps designed the device to achieve transcutaneous pacing, or external pacing. The device delivered gentle pulses of electricity directly to the patient's chest through wires sticking in the body to stimulate the heart to contract. If the patient was conscious, the current, although moderate, was considerably painful—that discomfort significantly enhanced by the wires in the chest. Records from the initial two years indicate that some patients, anxious over the pain, opted not to have the device used. Nevertheless, as a threshold device, Hopps's external pacemaker provided biomedical engineers critical data for developing more efficient devices once transistor technology and batteries were available.

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dures. The ensuing project, headed by Hopps, was a landmark moment in twentieth century medicine, the first cooperative venture of the fields of medicine and engineering, the birth of the field of what came to be called biomedical engineering.

Hopps understood the ambitious goal: externally apply an electrical stimulation to the heart that would duplicate the body's normal contraction, thus not damaging the heart as cardiac massage so often did. Also, unlike the quick jolt of adrenalin, the constant application of a steady (and low) voltage would avoid muscle and nerve damage and would ensure long-term stability rather than a quick fix. The application of the electrical current, in turn, not only could control the pulse rate but also could be used in emergencies to restart a stopped heart.

Work on the project was swift and efficient—Hopps drawing not only on his own practical sense of problem-solving but also on the significant resources of both the NRC and the Banting Institute. Initially, Hopps recognized that any successful prototype would need an electrode capable of administering the nanosecond pulses of current needed for such delicate work. He designed the first catheter electrode designed specifically for cardiac resuscitation and stimulation. The catheter electrode would be introduced through the right external jugular vein, and an accompanying electrical generator would maintain the circuit. The Hopps Pacemaker-Defibrillator was first tested in 1950, effectively the world's first artificial pacemaker. Hopps's pacemaker was boxlike, roughly 30 centimeters long and several centimeters high and wide. It was powered by a standard 60-hertz household current and delivered up to 220 volts. It was tested successfully on several canines before it was introduced into patient care. Given its size, its use was restricted to operating room procedures and postoperative care. By 1957, however, the model had been sized down sufficiently to be implanted into the chest, and the era of the portable pacemaker was underway.

Hopps returned to his position at the NRC until his retirement in 1979. During that time, in addition to further developing the pacemaker, he directed important research into devices to assist the blind, to help support and even correct muscular abnormalities in the disabled, and to use ultrasound as a noninvasive diagnostic tool. More to the point, given his international celebrity as the pacemaker became a foundation of cardiac care, Hopps became a tireless proponent of the new field of biomedical engineering, founding the Canadian Medical and Biological Engineering Society and serving on numerous international boards and commissions that encouraged the new field. He championed a variety of community causes in the Toronto area well after his retirement, most notably crusades to improve medical care for children and health-style changes to improve cardiac care among the elderly. Fittingly, in 1984, Hopps himself received a pacemaker, and another later in 1997. After his death in 1998, he was hailed throughout Canada for his visionary contributions to both medicine and engineering.

IMPACT

Hopps's acumen in solving the problem of electrical heart stimulation is widely credited for revolutionizing cardiac care and improving the quality of life for millions of heart patients, but there is more to Hopps's impact. It is difficult for a contemporary audience to appreciate the magnitude of Hopps's initial experimental prototype as an ethical issue—indeed, the moral implications raised by his pacemaker would become a central issue in the emerging field of biomedical engineering. Although such moral dilemmas never distracted Hopps, who saw the regulation of a heartbeat as a problem that electrical engineering could solve, they are part of his invention's legacy. Indeed, applying electrical stimulation to a faltering heart had been tried before—but its success had been overshadowed by fears of public outrage. In 1926, an Australian doctor, later identified as Mark C. Lidwell, had used a 16-volt electric current to stimulate the stopped heart of a stillborn in cardiac arrest. The procedure had worked, but fears of religious objections to doctors playing God kept the incident in hospital files until the mid-1960's, only after Hopps's work had made this kind of procedure routine.

In addition to raising thorny questions over interfering with the "natural" course of life, Hopps's pacemaker provides a significant example of how medical technology evolves at a remarkable pace. Because Hopps's first working model depended on vacuum tubes, it appears cumbersome to a contemporary audience. However, once Hopps had demonstrated the regulatory power of an electrical current applied directly to the heart as a way to stimulate rhythmic beating, engineers across the globe worked quickly to make the device portable, first as an external model that strapped to the chest but ultimately as the familiar battery-driven device inserted directly into the heart. The evolution of the pacemaker is a landmark case in the cooperation of engineering and medicine, a groundbreaking confluence that has led to major advances in areas as diverse as brain surgery, eye care, pulmonary treatment, and nerve damage repair.

—*Joseph Dewey*

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See also: Willem Einthoven; Wilson Greatbatch; Robert Jarvik; Paul Winchell.

GODFREY NEWBOLD HOUNSFIELD

English electrical engineer

Hounsfield researched, designed, and built the first computerized axial tomography (CAT) scanner, which uses X rays to obtain three-dimensional images of the internal organs of the body. The CAT scan, a noninvasive procedure, revolutionized diagnostic medicine, allowing doctors to locate tumors and other diseased tissues in the body.

Born: August 28, 1919; Newark-on-Trent, Nottinghamshire, England
Died: August 12, 2004; Kingston upon Thames, England
Primary fields: Electronics and electrical engineering; medicine and medical technology
Primary invention: Computerized axial tomography scanner

EARLY LIFE

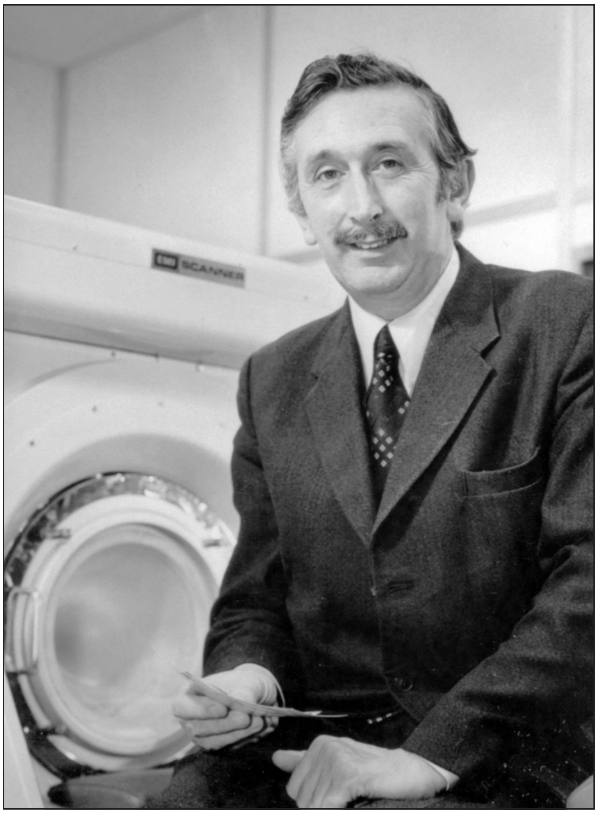
Godfrey Newbold Hounsfield (HOWNZ-feeld) was born in Newark-on-Trent in Nottinghamshire, England, in 1919. His early life was spent on his parents' farm, where he was fascinated by the farm machinery and electricity. Hounsfield learned at an early age how the machines worked and taught himself the fundamentals of electronics. He built electrical recording machines and radio sets, and he tried to fly off haystacks with a home-built glider. Some of his experiments were dangerous. He almost blew himself up while experimenting with water-filled tar barrels and acetylene to see how high they could be propelled by water jets.

Hounsfield had little interest in grammar school and, except for courses in science and mathematics, did not do well. After grammar school, he attended a vocational college and graduated with a degree in radio communication in 1938. He was interested in aviation, and at the outbreak of World War II he volunteered for the Royal Air Force (RAF). There he studied and later taught radar technology at the RAF's Cranwell Radar School. After being discharged from the RAF at the end of the war, he was given a grant to study at the Faraday House Electrical Engineering College, where he graduated in 1951 with a degree in electrical and mechanical engineering. That year, he obtained a position as an engineer at Electrical and Musical Industries (EMI).

LIFE'S WORK

At that time, EMI was primarily involved in sound recordings and selling records. The company had become very rich by publishing the Beatles' recordings and was looking to expand its business into other fields. Hounsfield's initial research was on radar and guided weapons, but his interest quickly turned to computers. He worked on memory systems, including core stores and tape decks. He was soon made a team leader and in 1958 helped design the first all-transistorized computer built in England, the EMIDEC 1100. At that time, transistors were very slow compared to vacuum tubes. Hounsfield was able to increase the speed of the transistors to that of vacuum tubes by driving the transistors with magnetic cores.

After these successes, Hounsfield was transferred to EMI's Central Research Laboratories, where he could pursue his own projects. His first project was to design and build a thin-film memory for computers that would hold one million words—a very difficult technical task. After considerable research, EMI decided that the project was not commercially feasible and told Hounsfield to


Godfrey Newbold Hounsfield with his computerized axial tomography (CAT) scanner. (©The Nobel Foundation)

Computerized Axial Tomography

In 1967, Godfrey Newbold Hounsfield conceived the idea for a machine that could create detailed images of the internal structures of the body by taking X rays at various angles. He realized that if X rays were taken perpendicular to each other, a cross section of the examined object could be obtained. If the X-ray beam was collimated and moved around the axis of the body with the X-ray detector opposite, the maximum information about that slice of the body could be collected. Further, by moving the body through the beam as the slices were recorded, the maximum data about the interior of the body could be obtained. The cross-sectional X-ray images could then be assembled by a computer to present a three-dimensional view more detailed than an individual two-dimensional X ray.

Hounsfield invented a density scale, now called the Hounsfield scale, to change signals from the detector into numbers that could be manipulated by the computer. The Hounsfield scale uses Hounsfield units (HU) and ranges from –1000 HU (air) to 0 HU (water) to +1000 HU (bone). The computer takes the numbers from the X-ray detector and solves a series of equations to reassemble the slices and to obtain an image of the interior of the body. The first computers were very slow, and producing a scan of the head took hours. Now, with much faster computers, a high-resolution scan of the entire human body can be obtained within minutes.

Hounsfield's computed tomography (CT), or computerized axial tomography (CAT), scanner was first used on a living patient in the fall of 1971. CAT scanners have since changed the world of medical imaging and now make it possible to measure accurately the position, size, and density of an object within the human body. It is an indispensable tool for localizing a cancer prior to surgery or radiation therapy. Although the procedure is expensive and has a higher radiation dose than an individual X ray, it has helped save thousands of lives.

think about some other research that he would like to do. He chose pattern recognition.

Hounsfield suggested that if one had various pieces of a pattern, it might be possible to reconstruct the image with a computer. He first put together a matrix of numbers representing an object and then scanned these numbers in slices. By connecting the slices together with a computer program, he was able to reconstitute the image. This worked very well, and he saw that by using a collimated beam of X rays and imaging a body in slices around its axis, he could put the slices together with a computer and obtain an image much superior to a conventional X ray.

Because Hounsfield worked for a commercial company, he had not been exposed to the academic literature and did not know of other work that had been done on X-ray computed tomography. Several years earlier, Allan M. Cormack, a South African physicist, had worked out the method of taking many X-ray images from different directions and putting the data together mathematically to form a much better picture than that obtained with conventional X rays. Unfortunately, computers at that time were not capable of handling such data, so it was not possible for Cormack to build a workable model.

Hounsfield's first prototype scanner was built on a lathe bed and took 160 parallel readings through 180 angles. The output was stored in a computer memory and then analyzed using an algebraic reconstruction technique that Hounsfield had worked out. His first tests were made on a preserved human brain and then a fresh cow brain from a butcher shop. The system worked well from the very beginning. After his first successes, he requested a grant from the Department of Health and Human Services to help develop the scanner. This money allowed him to perfect the instrument, and the first computerized axial tomography (CAT) brain scanner was installed in Atkinson Morley's Hospital in London. On October 1, 1971, doctors performed the first CAT scan of a living patient. This trial detected a cystic brain tumor in the patient.

In 1975, Hounsfield built a whole-body scanner and continued to develop the technology for the remainder of his career at EMI. Later, he was also involved in research into nuclear magnetic resonance (NMR) imaging. He retired in 1984 but continued as a consultant for several more years. He lectured in various countries but never felt comfortable speaking in public.

Hounsfield was a lifelong bachelor who lived modestly. He was a shy man, and his main interests were work-related. He lived a solitary life and liked to ski and take long walks in the mountains. He loved music, particularly jazz, and taught himself to play the piano. Though he had wealth and fame, Hounsfield spent little upon himself and never had a permanent residence until the mid-1970's.

Many honors and awards were accorded Hounsfield during his lifetime. He was made fellow of the Royal Society in 1975, and in 1976 was made a Commander of the Order of the British Empire (CBE). In 1979, he received the Nobel Prize in Physiology or Medicine together with

Dr. Allan Cormack for "developing computer assisted tomography." Hounsfield was knighted by Queen Elizabeth II in 1981.

Upon his death in 2004, Hounsfield's primary bequests were to his family members. After these bequests, he left the remainder of his money to the British Institute of Radiology to set up an annual Godfrey Hounsfield Lecture.

IMPACT

The invention of the CAT scanner by Hounsfield was the first major advance in medical imaging since Wilhelm Conrad Röntgen's discovery of X rays. An X ray is a two-dimensional picture that is most useful in observing dense objects such as bones. However, it is not sensitive enough to resolve tissues with different densities within the body and cannot distinguish between two organs that lay one above the other. Hounsfield's CAT scanner produced clearer images of soft tissues. After EMI built the first commercial CAT scanner and sold a few of the models to hospitals in England, the utility of the device became obvious.

The first CAT scanners could only scan small volumes and were designed to look for lesions or nodules in the brain that could not be seen by conventional X rays. The CAT scanners were bulky and expensive, but as transistors and integrated circuits became available, the scanners could be used for more than brain scans. Improvements were made to the X-ray detectors to improve the resolution. With more collimated X-ray sources and faster computers, scans can now be made in minutes.

By the year 2000, there were about seven thousand CAT scanners in use in the United States. The scanner is the instrument of choice for cancer diagnostics. Some researchers have claimed that there has been an overuse of CAT scans in the United States, unnecessarily exposing patients to radiation, which may increase their cancer risk.

—*Raymond D. Cooper*

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See also: Roscoe Koontz; Robert Steven Ledley; Wilhelm Conrad Röntgen.

ELIAS HOWE

American machinist

In addition to being the first American inventor to build a workable sewing machine and have it successfully patented, Howe combined with other sewing machine manufacturers to minimize lawsuits and maximize profits by sharing patents for fees to avoid mutually destructive competition.

Born: July 9, 1819; Spencer, Massachusetts
Died: October 3, 1867; Brooklyn, New York
Also known as: Elias Howe, Jr. (full name)
Primary fields: Household products; manufacturing
Primary invention: Sewing machine

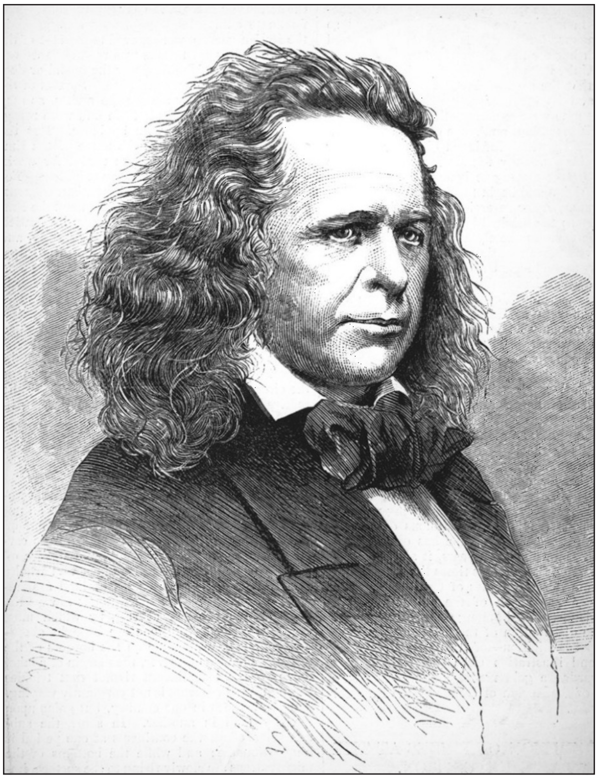
EARLY LIFE

Elias Howe, Jr., was one of eight children born to a poor farmer, Elias Howe, Sr., and his wife, Polly Bemis Howe. Among the Howe family, two of Howe's father's brothers were inventors. Elias, Sr., himself ran a gristmill and cut lumber, in addition to farming, to support his family. When Elias, Jr., was six, he worked along with his brothers and sisters sewing wires on cards by hand at home. This piecework, for a local cotton mill, brought in some extra money to help the family. His other work as a boy included repairs to his parents' farmhouse. He showed great patience and determination in his painstaking tasks, often repairing the farm machinery—work he enjoyed. The young boy's life, however, was not all work. Regarded as easygoing and companionable, he had several good friends. He attended school during the winter but spent the other seasons at work on the farm.

By the time Howe was twelve, his father realized that he could no longer feed and clothe him, so he was hired out to work on a neighbor's farm. This arrangement lasted for about one year but had to end when Howe's frailties interfered with his heavy chores. The youngster had been born small and frail, and he never had the endurance and strength necessary for hard labor, a fact with which he had to contend all of his life. He was also congenitally lame.

In 1835, Howe moved to Lowell, Massachusetts, where he found work repairing cotton-mill machinery. Although he was still a young man, he was admired for his advanced skill with machinery. However, the economic panic in 1837 forced the cotton mills in Lowell to close, and young Howe lost his job.

Howe next moved to Cambridge, Massachusetts, where he roomed with a cousin and worked as a foreman for a hemp-carding company; this job was boring and fatiguing, so Howe stayed for only part of a year. His next position was a fortunate one for him. He worked as a repairman for Ari Davis of Boston, a skilled watchmaker, who also made precision instruments for seamen and for the scientists at Harvard University. Davis's shop attracted many inventors, and it was here that Howe got the idea to invent a sewing machine. One day in 1839, he heard the loud-voiced Davis tell a customer who was struggling to invent a knitting machine that the invention of a sewing machine would make a man rich.



Elias Howe. (Library of Congress)

On March 3, 1841, Howe married Elizabeth J. Ames of Boston. In a few years, the couple had three children to support. To help her husband, Mrs. Howe did handsewing for her neighbors. Many evenings, Howe watched her sew, pondering how a sewing machine would work. In part from his fascination with machinery and in part from his desire to escape poverty and support his family, Howe became obsessed with the idea of inventing a sewing machine.

LIFE'S WORK

Howe quit his job at Davis's shop and moved into the attic of Elias Howe, Sr.'s house—now in Cambridge. There in 1843, working diligently, Howe was beginning to put together his first version of a sewing machine when a fire destroyed the house. A friend, George Fisher, took an interest in Howe's invention and generously funded him five hundred dollars for the equipment he needed; Fisher also boarded the Howes in his home.

From 1844 to 1845 (especially during the winter months), Howe worked at a feverish pace to complete a functioning sewing machine. He used no blueprints or sketches but worked from a mental design; he also used the trial-and-error method of putting his ideas into moving parts, often discarding pieces of the machine that had not worked to his satisfaction. One of his most serious challenges was the designing of the proper needle for his sewing machine; needles with holes at the head (as women use in hand sewing) did not work on the machine. Finally, Howe had a dream in which men were threatening to kill him with spears; he noticed that all the spears had holes near their points—this was his solution. Howe's machine sewed perfectly when he used such needles.

By April of 1845, Howe and his business partner Fisher had a machine that they could present to the public. A demonstration was held at the Quincy Hall Clothing Manufactory, where Howe, operating his machine, sewed at least five times faster than the best women hand-sewers. The stitching produced by Howe's machine was also neater and stronger than that done by hand.

Howe's sewing machine did not impress Boston's clothiers as a useful item for them to purchase. A few factors affected the marketing of Howe's invention to American industry. First, it was expensive—about three hundred dollars. Second, the hand-sewers would have to be retrained to work by machine, and their employers feared that they would refuse (the workers knew that the sewing machines would soon take most of their jobs). Finally, the clothiers already had cheap labor in their women workers, so they saw no need to buy machinery to do the sewing. Howe was also at a disadvantage in that the United States did not yet have a strong communication network. If news of his machine had reached major clothing firms in New York City, he may have found buyers for his invention.

When Howe realized that there were no eager buyers for his machine in the United States, he sent his brother Amasa Howe to London, England, to try to market it there. The British industries were more organized than the American ones at this time and were also more acquainted with manufacture by machine. In October of 1846, Amasa Howe sold his brother's sewing machine to William Thomas of London for £250. Thomas was a maker of corsets, shoes, and umbrellas, and he was also a dishonest man. He obtained a British patent for the Howe machine in his own name, rather than in Howe's as he had promised. Thomas also made a verbal agreement with Amasa to pay Elias a royalty on each sewing machine Thomas sold—an agreement that he ignored.

Howe's profits from the first sale of his invention quickly went to pay his debts. He found himself in poverty again and so accepted an offer from Thomas (still seemingly a fair man) to move to London and build for him a stronger sewing machine (presumably to sew leather for shoes). Howe and his family moved to a poor section of London, and he worked for Thomas for fifteen dollars a week. At the end of eight months, Howe had created the desired machine, and Thomas, not too graciously, ordered Howe to work as a repairman in his factory. Howe felt insulted and left.

The year 1848 was an especially difficult one for Howe. First, he had to be separated from his family. Un-

THE RISE OF THE SEWING MACHINE

In 1846, Elias Howe was awarded the first U.S. patent, number 4,750, for a functional sewing machine using a lockstitch design. The first patent connected to mechanical sewing had been issued in 1755 in England to the German inventor Charles Weisenthal for a needle that was designed for a machine. However, the patent was for the needle, not a machine—and the machine designed to use the needle may, in fact, not have existed. Many other inventors attempted to design a mechanical sewing device, but their machines were neither functional nor successful.

In 1830, a sewing machine was designed and manufactured by a French tailor, Barthélemy Thimonnier, to mass-produce uniforms for the French Army, but rioting tailors destroyed the machines. His design merely mechanized the hand-sewing operation, as it used one thread only and a hooked needle that made the same chain stitch used with embroidery.

In 1834, New Yorker Walter Hunt contributed a great improvement when he used a lockstitch. He never patented his method, however, because he thought that his invention might cause unemployment. When, twelve years later, Howe independently patented his sewing machine for "a process that used thread from two different sources," the device was on its way to becoming the modern sewing machine.

Howe's machine had a needle with a straight eye-point and transverse shuttle. The needle was pushed through the cloth and created a loop on the other side; a shuttle on a track then slipped the second thread through the loop, creating what is called the lockstitch. The technique proved highly successful, but Howe had problems defending his patent and marketing his invention.

Sewing machines did not enter mass production until the 1850's, when Isaac Singer built the first commercially successful machine. Singer "borrowed" Howe's lockstitch mechanism and became the largest manufacturer of sewing machines. In Singer's sewing machine, the needle moved up and down rather than the sideways, and power was provided by the operator, using a foot treadle. Previous machines were all hand-cranked. However, because Singer used Howe's lockstitch process and a needle similar to that employed in Howe's design, Howe sued Singer for patent infringement, and he won his case in 1854.

Allen Wilson developed the rotary hook shuttle. Ultimately, a design that incorporated the work of Howe, Singer, and Wilson was patented, and by 1860 more than 110,000 sewing machines were produced in the United States alone. Today, modern sewing machines span an enormous variety, for both in-home use and, even more important, for industrial purposes. However, Elias Howe's basic lockstitch operation remains unchanged.

able to support them, he sent them home to the United States, while he remained in England to build another sewing machine with the financial help of Charles Inglis, a relatively poor man himself. When this machine was finished, Howe sold it cheaply and also pawned his American patent papers on his first sewing machine (along with a working model), in order to buy ship passage back to the United States.

Howe landed in New York, where he found employment as a mechanic at a good wage, but he had held this job for only a few weeks when tragedy struck. His wife, having battled consumption for two years, was dying. Elias Howe, Sr., sent his son money to travel home to see Elizabeth before she died; his brother-in-law lent him a suit to wear to her funeral. Howe also learned that the few household goods he owned had been lost in a shipwreck on their passage from England. His father and neighbors helped him through this crisis, taking care of his children.

Ironically, at about this time, Howe learned of several American copies of his sewing machine, produced with total disregard to his U.S. patent. However, Howe remained persistent, patenting his first sewing machine on September 10, 1846, even though he had to mortgage his father's farm for the money that he needed to travel to Washington, D.C., to receive that patent.

Howe's legal patent made a considerable difference in the outcome of his life's work. He now elicited the aid of George Bliss, who had bought the 50-percent business interest in Howe's invention from George Fisher. Bliss and Howe employed the lawyers necessary to wage long court suits against the makers of American sewing machines. Howe wished to win a royalty from these manufacturers for each sewing machine they had sold in the United States; as the patented inventor of the machine, he had this right.

One of Howe's opponents in court proved to be a determined man himself. Isaac Merrit Singer, wishing to retain the fortune he was making from selling Singer sewing machines, hired help to refute Howe's claim that he was the rightful inventor. Singer located Walter Hunt of New York State, who had built a model of a sewing machine earlier than had Howe. Singer lost his case, however, when it was shown in court that Hunt's rebuilt machine did not work and that Hunt had never patented it.

Howe, after battling in court from 1849 to 1854, was victorious and, instantly, a rich man. All of his American competitors who were manufacturing and selling machines had to pay royalties to him. Soon, his income was about four thousand dollars a week. However, Howe was a generous man, sharing his new wealth with the friends and relatives who had helped him in his years of struggle. His one deep regret was that his wife had died before he gained his fortune. The humorous and fun-loving aspects of Howe's personality had left him at her tragic death.

Howe was, however, left with his dedication, which he used to good advantage in his remaining years. In 1865, in Bridgeport, Connecticut, he built a large, modern plant for the manufacture of sewing machines (later managed by his brother Amasa). Howe became a prominent and respected citizen of Bridgeport. When he volunteered to serve as a private in the Union Army during the Civil War (despite his age and infirmities) many young Bridgeport men were moved by his example and volunteered as well. Howe generously outfitted the entire Connecticut Seventeenth Regiment Volunteers, which he helped to organize; he even provided horses for the officers and paid the men when their army wages were delayed. Howe served in a Union Army camp near Baltimore, Maryland, but was forced to leave when his chronic frailty made it impossible for him to continue his duties as the camp's postmaster.

While visiting at his daughter's home in Brooklyn, New York, in 1867, Howe contracted Bright's disease; he never recovered and died October 3, 1867. The large factory he had built in Bridgeport, Connecticut, passed on to his son, who managed it until a fire leveled it on July 26, 1883. In the following year, the city of Bridgeport, in gratitude, erected a statue of Elias Howe, Jr., in their Seaside Park. He stands, hat in one hand and cane in the other, overlooking Long Island Sound. His face is large and solid, with a prominent nose, soft eyes, and firmly set lips—the face of a determined Yankee inventor.

IMPACT

With his invention of the sewing machine, Howe made a contribution to American industry that profoundly affected Americans' lives. The hand-sewn garments that women laboriously made for their families were replaced by mass-produced clothing that sold at affordable prices. Howe's invention also moved the making of many clothing items, including shoes, out of cottage industries and tailor shops and into manufacturing plants. The sewing machine became a reasonably priced, convenient piece of equipment that was also found in a large number of homes; there sewing became a creative task, rather than a painstaking necessity.

Howe also played an important role in another area of American industrial development. He, along with several successful sewing machine manufacturers, held a conference in Albany, New York, in 1856, with the purpose of avoiding further lawsuits. These manufacturers, known as the Combination, became the first American industrial group to form a patent pool; they shared one another's machine designs and improvements for a reasonable fee, rather than remaining rivals.

Howe's inventiveness, perseverance, and mechanical skill won for him many well-deserved honors in foreign nations, including a gold medal at the famed Paris Exhibition of 1867. His genius and Yankee know-how gained for this once poverty-stricken American the acclaim of a grateful nation and a grateful world.

—*Patricia E. Sweeney*

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See also: Beulah Louise Henry; Jan Ernst Matzeliger; Isaac Merrit Singer.

HUANGDI

Chinese military leader and agriculturist

Although shrouded in mythology and controversial as to his historical veracity, Huangdi is credited with many technological and cultural achievements, including the invention of boats, the horse-drawn chariot, ceramics, military armor, Daoist religious rituals, and the agricultural calendar allowing regular planting cycles and crop rotation. He also wrote important treatises on medicine and political theory. If his books are accepted as authentic, Huangdi is one of the earliest authors in known history.

Born: c. 2704 B.C.E.; China
Died: c. 2600 B.C.E.; China
Also known as: Shen Yen Huang-ti *or* Huang-ti (Wade-Giles); Yellow Emperor
Primary fields: Agriculture; medicine and medical technology; military technology and weaponry
Primary invention: Horse-drawn chariot

EARLY LIFE

Huangdi (huh-wong-dee) is regarded as a patriarch of China, a founding father of an ancient civilization. Moreover, many Han Chinese regard Huangdi as a direct ancestor and worship him as a god. Scholars of Chinese history agree that there is almost no reliable biographical information about Huangdi that can be separated from the mythology. The earliest dynasty of China verified by archaeological evidence is the Shang (1765-1122 B.C.E.), about one thousand years after Huangdi's reign. Whether Huangdi is a historical person or a mythological accretion of early accomplishments, his innovations and inventions tell the story of the earliest Chinese civilization. So pervasive is the reputation of Huangdi that Chinese history might cite the year 1911 C.E. as the year of a nationalist revolution led by Sun Yat-sen, the first year of the Republic of China, or the 4,609th year of the "Yellow Emperor," Huangdi. Huangdi earned the name "Yellow Emperor" because he is associated with the Yellow River (or the Huang He) and earth, which is the yellow element according to ancient Chinese cosmology.

Huangdi is believed to have come from the central heartland of the Yellow River basin. Nothing is known of his family background, but some historians regard Huangdi as the third of the first five Chinese sovereigns. The Age of the Five Rulers, or Legendary period, is thought to have lasted for six hundred years in the middle of the third millennium B.C.E. According to legend, when the early ruler Shennong died, his court official Ch'ih Yu led a rebellion of the southern barbarians, which was put down by Huangdi. Huangdi successfully suppressed the rebellious tribes and incorporated the new regions to the south beyond the Chang (Yangtze) River into the Chinese Empire. He also extended the reach of China to include regions in the eastern province on the Pacific, to the north, and to the western frontier zone including deserts and mountains. He married as his primary wife Leizu, who was the daughter of a local feudal lord. In the tradition of ancient China, Huangdi undoubtedly kept many subsidiary wives who worked in the silkworm industry.

Huangdi's role in religion adds to his cultural importance. Huangdi is regarded as a founder of Daoism who lived centuries before Laozi (Lao Tzu), the traditional "old master" and scribe of the sixth century B.C.E. text the *Dao De Ching*. Daoist practitioners regard Huangdi as the first master who directed the teachings of Laozi, ascended to immortality, and attained the status of patriarch of the nation.

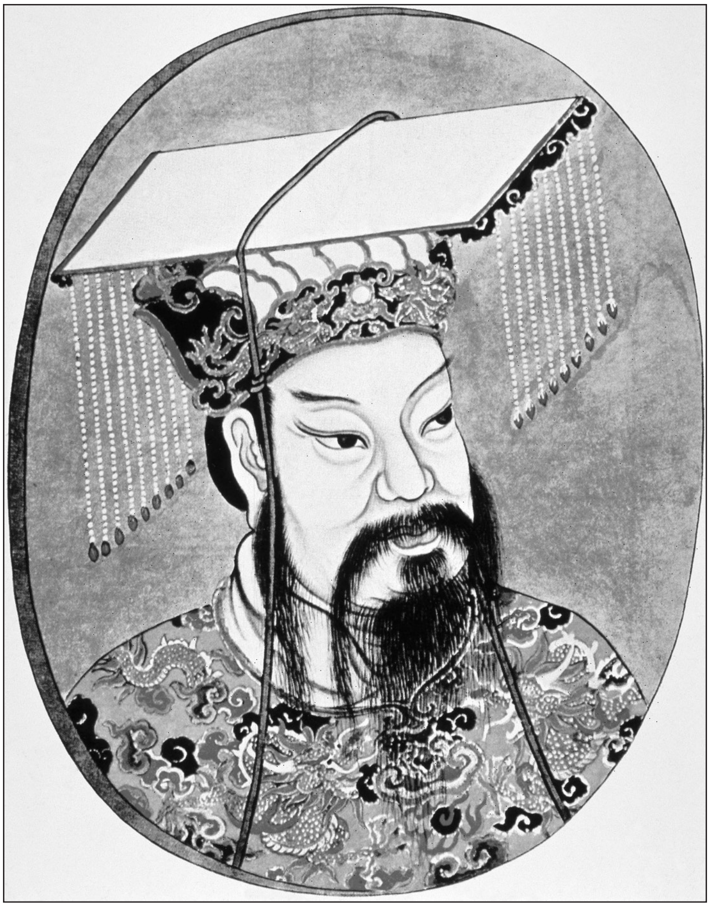
LIFE'S WORK

Huangdi's accomplishments are so numerous as to include many basic ingredients of civilization. Scholars regard his inventions as possibly attributed to an amorphous "grandfather" of China. Scribes during the much later Warring States period of the Zhou Dynasty might have invented Huangdi to record traditional creation stories and myths in a human form. Early Chinese historians might have created the Age of the Five Rulers in order to give their history prestige, longevity, and continuity in the way Roman historians might have invented their early Etruscan monarchs.

Whether historical or mythological, Huangdi is responsible for much of the material culture of Bronze Age China. For example, he is said to have perfected bows and arrows, military armor, and armed boats. Huangdi is thought to have unified the heartland of ancient China, defeating competing tribes to stabilize the region politically. He is credited with clearing swampland and cutting back forests in order to make room for the domestication of animals such as pigs, cows, horses, and goats. Huangdi is also thought to have invented the wheeled cart for transport of farm products and the chariot for war.

In the realm of religion and philosophy, he is said to have received instruction from three female Daoist "immortals" who informed him about the practice of yoga as a curative physiological and religious ritual that would ensure a long life and fertility. In the annals of legend, Huangdi himself achieved Daoist immortality and ascended to heaven on the back of a dragon accompanied by his courtly ministers and seventy female servants.

Some of Huangdi's most astounding contributions to civilization are found in the field of medicine. Huangdi is credited with the invention of acupuncture and the scientific study of human anatomy and physiology. European techniques of healing reached China in the seventeenth century C.E. through Jesuit missionaries, but the early Christian travelers discovered a much older tradition of Chinese traditional healing and acupuncture described in *Huangdi neijing*. Though it is impossible to prove definitive authorship, Huangdi might have written the first treatise on health and sickness and one of the oldest known books in the world. In fact, some scholars attribute the invention of writing to Huangdi for the express purpose of recording his medical knowledge. The *Huangdi neijing* is the foundation of traditional Chinese medicine. Huangdi's book consists of anatomical and physiological charts, methods of diagnosis, description of diseases, therapeutic methods, acupuncture methods, and moxibustion charts (which depict needle placement sites). The book contains illustrations of internal organs such as the kidneys, the liver, the digestion system, as well as the blood vessels and circulatory system.



Huangdi, the "Yellow Emperor." (The Granger Collection, New York)

Huangdi is also credited with one of the earliest treatises on the fundamental Chinese concepts of yin and yang. Huangdi describes yin and yang as the basis for the order of the universe and the foundation of health. Balance and harmony depend on keeping the forces of yin and yang in healthy proportions. In each field of endeavor and human attempt to shape the environment, yin and yang can be seen not as opposed forces but as intertwined tendencies. Yin is thought to be the "female principle," associated with darkness, soft shapes, moist earth, cool water, and the Moon. Yang is the "male principle," associated with items that are light, hard, dry, warm, and the Sun. In Huangdi's theory of health, the human body is divided into the lower, middle, and upper regions. Each of these is in turn subdivided into three sectors containing elements of heaven, earth, and humanity. Each subdivision was held by Huangdi to be composed of one part yin and one part yang; thus Huangdi saw the human body as totally in harmony with three parts of each principle. Treatment of certain diseases depended largely on the location within a particular region of yin and yang, so knowledge of the anatomical structure was essential. For example, the "absolute" and "lesser" versions of yin and yang were said to control the liver, gall bladder, heart, small intestine, spleen, and stomach.

IMPACT

If regarded as a historical person, Huangdi had a profound impact on ancient China and invented most of the material culture as well as the most influential theories of politics and medicine. If Huangdi is viewed as mythological, his accomplishments are still valuable because they testify to the high level of civilization attained in China during the third millennium B.C.E. While the Greeks and Europeans were living in primitive circumstances, the Chinese of 2600 B.C.E. had invented the building blocks of civilizations: wheeled carts, pottery, and a dependable agricultural calendar. The Chinese had invented writing and started to record their theories of human health, religion, and politics in books attributed to Huangdi.

—*Jonathan Thorndike*

THE HORSE-DRAWN CHARIOT

According to legend, Huangdi is credited with the invention of the horse-drawn chariot, which might have enabled him to transport soldiers and to stage offensive maneuvers against the rebellious southern barbarians in the early years of his reign. However, archaeologists speculate that the chariot actually entered China from the ancient Near East or Mesopotamia during the much later Shang and Western Zhou periods or around 1200 B.C.E., approximately the same time as the legendary fall of Troy. The archaeological evidence for the development of the chariot in China is quite good, and the theory that it was imported from the Near East is based on the similarities of archaeological finds in both locations.

Whether or not this invention can be attributed to Huangdi is less important than the impact the chariot had on military technique and battle strategy. The military supremacy of the chariot against foot soldiers was based on its speed and maneuverability. Troops could be dispatched quickly from cities to areas of need, and information could travel more quickly back and forth from the front line to the commanding officers or kings. These early Chinese chariots were similar to their Near Eastern brethren in design, consisting of a chariot box, axle and wheels, and harnessing mechanism. The lightness of the chariot was its prime innovation when contrasted with lumbering ox-drawn wagons for carrying farm goods and supplies. The chariot box was rectangular and enclosed by a railing that rose to a height of approximately 45 centimeters (17.7 inches). It was open in the rear, allowing for quick entry and exit. The light design allowed for two or three riders between two wheels made with six to eight spokes and connected to a central spine, or yoke. The single wheel axle could be moved toward the horses to balance out the weight of the soldiers and provide some shock absorption, especially for rough terrain. The chariot would remain the prime advantage in military technology in the ancient world until the introduction by the classical Greeks of the hoplite (heavily armed warrior) and the phalanx combat strategy in the fifth century B.C.E.

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See also: Cai Lun; Hero of Alexandria.

DAVID EDWARD HUGHES

British musician and physicist

Hughes's invention of an improved carbon microphone was an important step in the development of the telephone. He also invented a printer that could be used with a telegraph, and the induction balance, used to detect metals.

Born: May 16, 1831; London, England
Died: January 22, 1900; London, England
Primary fields: Communications; electronics and electrical engineering
Primary inventions: Loose-contact carbon microphone; induction balance; printing telegraph

EARLY LIFE

David Edward Hughes was born into a family of talented musicians in London, England, though he grew up and began his career in the United States. He and his three siblings were all considered child prodigies, and they performed concerts with their father throughout England. The children were encouraged to develop their skills on different instruments; Hughes played piano, harp, violin, and concertina, and he composed music for all four. The family emigrated to the United States when Hughes was nine, arriving in New York City on October 8, 1840. They performed in New England, Canada, the West Indies, and once at the White House before buying a farm in Virginia and settling there. While only nineteen years old, Hughes was named a professor of music at St. Joseph's College, a school for women in Bardstown, Kentucky, thanks to the support of his piano teacher.

In addition to his interest in music, Hughes was fascinated by the physical sciences and by philosophy. With equipment that he built from common objects, and with little mathematical training, he conducted experiments with electricity and with various ways of sending and receiving signals. When he was twenty years old, he was named chair of the Natural Science Department at the college.

LIFE'S WORK

In 1855, at the age of twenty-four, Hughes obtained his first patent, for a telegraph instrument that printed messages. The invention was something of an accident: He had been trying to create a machine that could transcribe musical notation as music was played, and his first keyboard was adapted from a piano. Each key corresponded to a letter of the alphabet, and so a person operating the Hughes printer could, in effect, type a message and have it printed out in words—not in dashes and dots, as in the Morse telegraph system—at the receiving end. Hughes sold the North American rights to a group that became the Western Union Telegraph Company, achieving his first commercial success. His machine became a popular replacement for the Morse system in the United States. Hughes returned to England to try to sell his system to the Electric Telegraph Company there, but the company preferred the Morse system. He moved next to Paris, where the French government agreed to give his system a yearlong trial. The trial was such a success that Napoleon III named Hughes a Chevalier of the Legion of Honor, and his system of telegraphy was quickly adopted throughout the Continent. While in Paris, Hughes met Anna Chadburn, an artist from New Hampshire. Together they moved to London in 1877 and married. Thanks to Anna, Hughes's notes and papers were saved after his death. The couple had no children.

Hughes had made enough money from the printing telegraph that he could devote his time to experimentation without needing to earn an income. Still, he preferred to work with common items, including nails, jam pots, cigar boxes, and scraps of wire as he experimented. His experiments in electricity and magnetism led to several scientific papers, which he presented before the Royal Society in London, and he was eventually named a fellow of that group. In 1886, he became the president of the Institution of Electrical Engineers in London.

With the invention of the telephone in 1875, Hughes joined the legion of professional and amateur scientists working to improve the device and make it commercially viable. He built his own telephone at home according to the prevailing designs; when he repaired a loose connection and lost a sound, he realized that a loose contact was actually preferable for transmitting electromagnetic signals. Putting granules of carbon in loose contact with two plates, he invented the loose-contact carbon microphone. On May 8, 1878, Hughes demonstrated to an astonished Royal Society that his microphone could amplify a whisper so that it could be heard through a room. He made a public announcement on June 9 of that year, inviting others to refine his work. He refused to file a patent, so that the work of other innovators would not be limited.

As part of his experimentation with sound and electromagnetism, Hughes invented the induction balance. It consisted of two coils connected to a battery and a telephone; when one of the coils was disturbed by the presence of a conducting metal object, the induction balance produced sound. Hughes used the device as a tool for producing and amplifying sound as he developed the carbon microphone, but the induction balance later became useful in producing metal detectors.

Not all of Hughes's findings were accepted by fellow scientists. When he began work on the telephone, he was curious to see how far he could send a signal. On February 20, 1880, he demonstrated to the Royal Society a device that sent and received radio waves. His conclusions were dismissed by the group, which declared that it was simple induction, not radio waves, that caused Hughes's signals. Hughes decided not to pursue this project further, and he never published his findings. Decades later, other scientists duplicated his work and developed the wireless telegraph.

Hughes died in London on January 22, 1900. He had lived simply all his life, leaving behind a large fortune,

THE CARBON MICROPHONE

After Alexander Graham Bell's first electromagnetic telephone transmission in 1875, the rush to develop a better telephone system was dramatic and contentious, and popular histories credit at least three different men with the invention of its important carbon microphone. Emile Berliner claimed to have invented it in 1876, and he sold his patent to the American Bell Telephone Company. Thomas Alva Edison filed a competing patent claim in 1878, and British and American courts ultimately supported Edison. Still, many sources, including the venerable *Encyclopedia Britannica*, credit Hughes with the invention.

The earliest device used a carbon ball between two metal plates to convert sound energy to electrical energy. As sound waves hit the outer plate, or diaphragm, they changed the pressure on it, which in turn changed the pressure on the carbon, causing the electrical resistance between the plates to change. Edison's telephone system passed an electrical current through the device and exploited the resulting changes in the current. Edison's and Berliner's microphones, which indeed predate Hughes's, are also known as "carbon-button transmitters." Hughes's improved version is the loose-contact carbon microphone. Hughes proved the importance of having a loose contact rather than a tight one between the two surfaces. He also tested various materials to determine which was best for creating resistance, concluding that loose grains of carbon produced the best sound quality. To distinguish his transmitter from Edison's, he brought back a disused term and called his instrument a "microphone." Hughes did not seek a patent for his invention. His microphone became the standard, and he, Edison, and others continued to work separately on improvements to the carbon microphone.

The carbon microphone solved the major problem of the telephone up to that time: weak sound. Although several inventors worked on applying Hughes's principles to Bell's telephone, it was again Edison who secured and defended the patent. Because of its ability to amplify sound, Hughes's loose-contact carbon microphone made possible the modern telephone, the hearing aid, the AM radio, and public-address systems. It continued to be the best device for amplifying sound until the 1920's, when the vacuum tube, which was superior in many ways but which required more power and so also required heavy batteries, began gradually to replace it in uses for which easy portability was not important. Nonetheless, the carbon microphone remained cheaper and easier to transport. It was used in telephone systems until the 1980's, while newer devices, including the transistor, replaced the carbon microphone in hearing aids and radios. Carbon microphones were still in use in the twenty-first century, however, in communications systems where higher-voltage systems would present a hazard, such as in mining or in the chemical industry, and as a backup for certain military communications systems. The telephone, made possible by the invention of the carbon microphone, is one of the most important means of communication throughout the world.

most of which he bequeathed to the Royal Society, the Paris Academy of Science, the Institution of Electrical Engineers, and four area hospitals.

Impact

In his time, Hughes was one of the most famous scientists in Europe, although he never received much recognition or praise from his native England. He was awarded several important awards for his work, including a Grand Gold Medal at the Paris Exhibition in 1867, the Royal Society Gold Medal in 1885, and the Albert Medal from the Royal Society of Arts in 1896. He was knighted or awarded medals from the governments of Austria, Bavaria, Belgium, France, Italy, Russia, Spain, Switzerland, and Turkey. In spite of his fame and his wealth, however, he remained known for his humility and generosity. He refused to take out a patent on his carbon microphone, believing that the invention should belong to the world—and the world profited from it. Similarly, he is now acknowledged as the first person to send and receive radio waves, but he declined to take credit or demand payment when Guglielmo Marconi built on his work in developing the wireless telegraph, leaving it for later generations of science historians to credit him for his important contributions to telegraphy.

It is no exaggeration to say that Hughes's inventions, especially in communications, changed the world. His printing telegraph quickly became the standard in Europe. The telegraph in turn made it possible for trains to run efficiently over great distances, for businesses to make decisions quickly based on a rapid flow of information, and for ordinary people to receive important news quickly and inexpensively. It was the only means of sending messages quickly over a long distance until 1877, when the telephone began to replace it. The telegraph did not immediately cease to be useful, however. The Western Union Telegraph Company, which used the Hughes printer until the 1930's, sent its last telegraph in 2006. Hughes also made important contributions to the development of the telephone, which, until the rise of personal computers and the Internet, was the most important means of communication worldwide. Finally, Hughes's induction balance led to the development of the metal detector, which has been used by militaries and hobbyists to locate missing objects and is still used in airport security systems.

—*Cynthia A. Bily*

Further Reading

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See also: Alexander Graham Bell; Emile Berliner; Thomas Alva Edison; Elisha Gray; Guglielmo Marconi; Samuel F. B. Morse; Charles Wheatstone.

MILLER REESE HUTCHISON

American engineer

Hutchison utilized his engineering expertise to invent numerous devices, notably hearing aids and innovations with communication, transportation, and military applications, and to influence Thomas Alva Edison's policies while serving as the chief engineer of that inventor's laboratory.

Born: August 6, 1876; Montrose, Alabama
Died: February 16, 1944; New York, New York
Primary field: Electronics and electrical engineering
Primary inventions: Acousticon; Klaxon horn

EARLY LIFE

Miller Reese Hutchison (MIHL-ur REES HUHT-chih-suhn) was born on August 6, 1876, in Montrose, Alabama, a community on the east side of Mobile Bay. His father, William Peter Hutchison, worked as a broker in Mobile. Hutchison's mother, Tracie Elizabeth (Magruder) Hutchison, was the daughter of affluent landowners who lived near Tuskegee, Alabama. Hutchison grew up in a house near the Hutchison Hotel, which his paternal grandmother had developed as a resort.

When he was seven years old, Hutchison began attending private school in Mobile. Intrigued by electrical and mechanical processes, he explored area machine shops, powerhouses, and foundries, gaining experience with technological devices, comprehending how they functioned and appreciating their practical applications. At home, Hutchison attempted to make batteries, accidentally creating acid holes in carpets. By 1889, Hutchison enrolled in Marion Military Institute, then took classes at Spring Hill College and the University Military Institute at Mobile. At the age of fifteen, he envisioned his first invention—a device to protect communication wires from electrical storms. He filed for a patent on May 25, 1895.

During 1895, Hutchison moved to Auburn to take electrical and mechanical engineering and machine design courses at the Alabama Agricultural and Mechanical College (now Auburn University). Faculty and administrators at that school encouraged innovation, establishing laboratories for electrical and engineering work. Hutchison was surrounded by progressive scientists and engineers who conducted early X-ray experimentation and applied electricity to such industrial uses as ginning cotton. Hutchison constantly contemplated ideas for new inventions. He received a U.S. patent for his first invention on November 12, 1895.

During academic breaks, Hutchison worked in Mobile machine shops. In 1896, he built an electrical X-ray device at the Mobile Light and Railway powerhouse. Hutchison hosted X-ray demonstrations, showing audiences bones in his hands and feet. He considered becoming a surgeon but decided that he preferred being an inventor. A member of the class of 1897, Hutchison left college without graduating in order to focus on engineering endeavors.

LIFE'S WORK

In summer of 1897, Hutchison initially visited Thomas Alva Edison's laboratory. During the Spanish-American War, Hutchison secured employment with the U.S. Light House Service as an electrical engineer in charge of the Seventh and Eight Districts, placing cables and mines to impede enemy submarines from entering Gulf Coast ports from Key West, Florida, to Galveston, Texas. He then resumed electronic work in his Mobile laboratory and attended classes at the local Alabama Medical College to study physiological aspects of hearing and ear anatomy to improve his hearing aid inventions. In 1902, he received a patent for the first electrical hearing aid, which he called the Acousticon.

Hutchison moved to New York City, where he established a laboratory and married Martha Jackman Pomeroy. They had four sons. Beginning in 1904, Hutchison applied his engineering knowledge as a consultant for New York City businesses. He devoted his days to financial work and invented at night. That year, St. Louis Exposition officials designated Hutchison as honorary commissioner of the Department of Electricity for that fair, presenting him with two medals.

By 1906, Hutchison envisioned his most lucrative invention, the Klaxon horn. While driving in Newark, New Jersey, Hutchison pushed his automobile's horn when a pedestrian ran onto the road. He realized that a horn's sound should be loud, not pleasant. Hutchison filed an application for his electric horn design in 1906, receiving a U.S. patent three years later. By 1912, General Motors had equipped its stock, over 150,000 vehicles, with Hutchison's horn, providing Hutchison over $40,000 in royalties. Hutchison gave Edison a Klaxon horn. Edison admired Hutchison's excitement for invention and his energetic personality, and the inventors formed a professional friendship, while investigating methods to strengthen storage batteries and strategies to sell them.

By 1908, Hutchison had invented an electronic tachometer to calculate a ship's velocity. He described that invention to Admiral George Dewey, President Theodore Roosevelt, and significant naval officers. The charismatic Hutchison convinced both U.S. and foreign naval officials to outfit submarines with Edison's batteries, which he stressed extended underwater range possibilities. As an Edison Storage Battery Company representative, Hutchison received commissions on battery sales.

In 1911, Edison chose a man named Donald Bliss as his Engineering and Experimental Department laboratory's chief engineer. Although skilled technically, Bliss lacked administrative capabilities. In April of that year, Edison privately invited Hutchison, whom he called "Hutch," to conduct business and research at that West Orange, New Jersey, laboratory and act unofficially as his chief engineer and spokesperson for Thomas A. Edison, Inc. (TAE), stating that Hutchison should be ready to take control if Edison's health failed or if he died.

When Edison needed money to maintain the laboratory, Hutchison loaned him $50,000. Hutchison drove Edison to meetings and sporting events, and they often debated topics all night. Hutchison met Edison's business associates, including J. P. Morgan, Jr. During meetings, Hutchison relayed messages in Morse code to Edison by touching Edison's leg or wrist. In 1912, Edison formally named Hutchison as chief engineer to oversee that laboratory. In addition to managing laboratory conditions, equipment, and personnel, Hutchison offered advice to adjust Edison's kinetophone, which did not perform well because of film and sound losing synchronicity. He served on the Naval Consulting Board, which Edison chaired and which was established to seek inventions useful for military applications, designating that work as his occupation on his World War I draft application.

Hutchison quit the Edison Storage Battery Company on New Year's Day, 1917, and established the Hutchison Company to concentrate on selling Edison batteries internationally as the only distributor of that technology. He resigned his TAE position in July, 1918, because of pressure from Stephen B. Mambert, a TAE executive, who claimed that some government officials preferred direct transactions with TAE, not Hutchison, to purchase Edison's products. The aging Thomas Edison

THE ACOUSTICON

A hometown friend's deafness inspired Miller Reese Hutchison to design a battery-powered hearing aid in the mid-1890's. Hutchison wanted to assist Lyman Gould to hear, hoping that his mute friend could speak after he heard sounds. Hutchison designed his hearing aids based on his knowledge that most hearing loss occurred because of auditory nerve problems or inflexible bones in ears that hindered hearing and speaking. Hutchison's device, incorporating an earpiece and transmitter, helped Gould hear several words Hutchison said to him, but Gould remained silent, content with being able to hear.

Hutchison refined his hearing aid, with intentions of marketing it, and named it the Acousticon, which he displayed to audiences in various forms as he altered its design. He focused on extending battery life to power his hearing aid and on reducing the size of the device, which began as a large wooden box containing the aid's components. Because the Acousticon performed the functions of the middle ear, its basic structure included a microphone, which collected sound waves that then vibrated on a diaphragm for amplification and transmission to earphones.

In November, 1901, Hutchison first filed for a hearing aid patent, which was issued the next year. He was the first inventor to create and market an electric hearing aid. His Akouphone Manufacturing Company in New York produced and distributed several hundred thousand Acousticons in the United States and Europe. Hutchison traveled to Paris and London in 1902 to demonstrate his hearing aid to scientists and royals, including Queen Alexandra, who was deaf, at Buckingham Palace. She presented Hutchison a gold medal honoring his inventiveness. In 1904, Thomas Alva Edison's wife purchased an Acousticon for Edison, who was partially deaf. Although Edison noted flaws in the Acousticon, he also praised it for helping him to hear a music concert.

The Acousticon's success motivated Hutchison to invent related devices, including the Massacon for physicians to massage ear drums with repetitive sounds that vibrated from a diaphragm and hit the middle ear. The Hutchison Acoustic Company first manufactured and sold Massacons in late 1902. This invention was referenced almost one century later in U.S. Patent number 5,788,656, an "Electronic Stimulation System for Treating Tinnitus Disorders" (1998), invented by Alfonso Di Mino. By May, 1905, Hutchison had received a patent for a device and procedure to test for deafness, evaluating hearing ability in order to select effective hearing aids.

Later inventors incorporated some of Hutchison's concepts to use battery-powered stimuli in smaller hearing devices worn externally or cochlear implants surgically placed inside ears.

did not defend his friend, and Hutchison sold his distribution rights to TAE.

After leaving TAE, Hutchison initially considered World War I military technological needs. He continued inventing and securing patents in the 1920's and 1930's. In 1921, he demonstrated a supercannon from his Woolworth Building laboratory, emphasizing that weapon's potential three-hundred-mile range. He also created a compound to reduce carbon monoxide in fuel exhaust. After his son, Harold, died in an April, 1928, airplane crash, Hutchison developed the motor-vita for enhanced aircraft performance. He experimented with that invention in his personal plane. Hutchison also devised a film-processing technique to clarify sounds in motion pictures, recording as many as twelve thousand sound vibrations per second.

Hutchison wrote articles for periodicals, including *Proceedings of the Institute of Radio Engineers*, and two booklets, *A Series of Twelve Non-technical Letters on the Edison Storage Battery* (1912) and *The Submarine Boat Type of Edison Storage Battery* (1915). In 1944, he died at the New York Athletic Club, where he resided during retirement.

IMPACT

Hutchison's attitude regarding invention, embracing all aspects, from designing and revising inventions to marketing and selling them, contributed to his successes. His willingness to promote his innovations assured profits, which financed his continued inventive pursuits and secured respect from Edison and many industrial and political leaders. Hutchison sold several hundred thousand horns and hearing aids, which improved the quality of life for many people. Industries adopted elements of these inventions as standards for later versions of horns installed in vehicles or basic hearing aid designs.

Perhaps Hutchison's most significant achievement as an inventor was how he affected Edison. For almost one decade, Hutchison's close proximity to Edison enabled him to shape laboratory and business decisions more than TAE executives. Because of his association with Edison, Hutchison expanded his contacts with military and political leaders, voicing concerns about technology used in warfare and inventions that could strengthen U.S. defenses.

Many inventors valued Hutchison's insights regarding innovations, incorporating fundamental ideas and technology he devised into their inventions. Several inventors' patents referenced some of Hutchison's patents soon after his inventions became public. References to Hutchison's patented inventions appeared in patents throughout the twentieth century and into the early twenty-first century, indicating the sustained awareness of Hutchison's work over a century since his first inventions were created. Recognizing Hutchison's influence on modern inventors, the Edison National Historic Site's archive preserves Hutchison's diary and correspondence he wrote while employed by Edison.

Scientific groups in the United States and Europe honored Hutchison with awards. When he returned to his alma mater at Auburn in June, 1913, to donate a wireless station, his gift initiated the first wireless telegraphy course taught in the region. In recognition of Hutchison's professional achievements, that college granted him an electrical engineering degree. His legacy continues in Auburn's pioneering wireless engineering program, which develops innovations for twenty-first century telecommunications advancements worldwide.

—*Elizabeth D. Schafer*

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See also: Georg von Békésy; Alexander Graham Bell; Thomas Alva Edison.

CHRISTIAAN HUYGENS

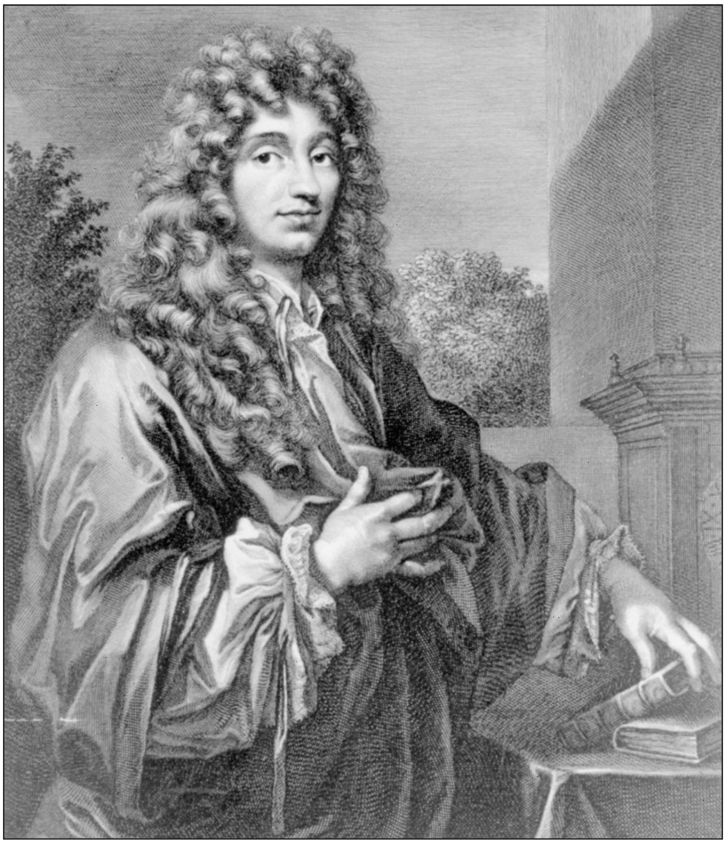
Dutch mathematician, astronomer, and physicist

Huygens developed new lens-grinding techniques with which he created more accurate telescopes; invented the most accurate timekeeper to date, the pendulum clock; and proposed a wave theory of light.

Born: April 14, 1629; The Hague, United Provinces (now in the Netherlands)
Died: July 8, 1695; The Hague, United Provinces (now in the Netherlands)
Primary fields: Astronomy; mathematics; optics; physics
Primary inventions: Pendulum clock; lens-grinding techniques

EARLY LIFE

Christiaan Huygens (KRIHS-teeahn HOY-gehns) was the second son of Suzanna van Baerle and Constantijn Huygens, the important Dutch poet and statesman who, from an early age, encouraged his son's academic interests by hiring specialized tutors, including the mathematician Jan Jansz de Jonge Stampioen. In 1645, Christiaan matriculated in law at the University of Leiden, where he also studied mathematics under Franz van Schooten as part of the well-rounded general studies curriculum considered necessary for the pursuit of a law degree. After two years at Leiden, he transferred to the newly founded College of Orange in Breda, where he completed his degree in 1649. Through an introduction from his father, he entered into correspondence with the Parisian mathematician Marin Mersenne, who first introduced the young Huygens to the problems of pendular motion by asking him to calculate the pendulum's center of oscillation. Huygens also traveled abroad, where he joined international scientific and mathematical social circles. By 1651, he had published his first mathematical paper on the ancient geometric problem of quadratures (calculating the area of a curve). After publishing a few more mathematical papers, in 1655 he befriended Ismael Boulliau and other astronomers in Paris. It was also in this decade that he contributed to van Schooten's 1659 annotated translation of René Descartes' *Géométrie* (1637), corresponded with its author, and, with Blaise Pascal's encouragement, himself published the first book on prob-



Christiaan Huygens. (Library of Congress)

The Pendulum Clock

The pendulum clock revolutionized timekeeping in Western Europe by making it much more precise: Instead of accuracy within about fifteen minutes per day, clocks became accurate within about fifteen seconds per day. Although the rudimentary idea of the pendulum clock may be credited to Galileo as early as 1637, it was Christiaan Huygens, working independently, who developed the functional models that would change the way clocks were generally made.

Since the invention of the mechanical clock in the thirteenth century, before Huygens all clocks used a verge escapement to regulate their rate. Pallets attached to one end of the verge were pushed by the teeth of the last wheel of the going train. The other end of the verge was attached to a balance wheel, or foliot. The action of the teeth and pallets rotated the balance wheel in one direction and then in the other, and this motion slowed down and regulated the going train. However, verge escapements were not very accurate because the oscillation period was faster with heavier weights or a tighter spring.

Huygens's great discovery was to use the pendulum as a regulating device. Instead of pallets attached to the verge, the pendulum's shaft regularly hit a crutch attached to the balance wheel, thereby forcing the clock's going train to follow its beat. In order to make this possible, Huygens turned the clock's mechanism 90° so that the balance wheel oscillated vertically. The pendulum itself was repeatedly nudged into motion by the force exerted by weights on the clock's going train, its swing being regulated by a small movable weight. The pendulum shaft was attached to the back of the clock to keep the pendulum as free as possible from interference. As the period of a pendulum swinging freely according to a circular path varies according to the magnitude of its swing, the arc of the pendulum itself was guided by curved metal "cheeks" placed on either side of the suspension cord, effectively shortening the length of that cord and causing its bob to swing according a noncircular, cycloidal motion. As the pendulum swung upward around the cheeks, it swung faster—just the right amount faster so that if one began the pendulum's swing at any point on the curve, the force of gravity would carry it to the bottom at the same time, a property called isochronism. Huygens had quickly understood that circular pendulums were not isochronous unless they were of very small amplitude so that the difference in curvature was negligible. Later pendulum clocks would be refined by anchor and other sorts of escapements that removed the need for the cycloidal cheeks by sufficiently limiting the pendulum's arc.

ability theory, *De ratiociniis in ludo aleae* (1657). Although Huygens did not yet hold a research position, his career choice in the areas of mathematics and physics was made by this time, and he was about to enter the most productive period of his life.

Life's Work

Huygens gravitated toward subjects in which his mathematical studies were associated with physical realities and real-world needs. His friendship with astronomers and his interest in dioptrics inspired by Descartes led him to improve the telescope by developing, with his older brother Constantijn, new methods and a new machine for grinding lenses that diminished aberration. With these lenses, he made an improved telescope, discovered Saturn's moon Titan (1655), and solved the mystery of Saturn's true shape (1656), correctly observing that the planet was surrounded by flat rings set at an angle to its axis.

Meanwhile, he had turned to the problem of determining longitude at sea, for which more accurate timekeepers were needed. He devised a new type of clock, regulated by a pendulum. The clock's design was worked out empirically in 1656 and patented in 1657. On June 16, 1657, the Dutch government granted Salomon Coster the exclusive "privilege" of making Huygens-designed pendulum clocks. Many existing clocks were also converted to operate with pendulums. After Coster's sudden death in 1659, French and English clockmakers copied Huygens's design, as Huygens had not been successful in gaining a patent in those countries.

In the last months of 1659—the period in which he formulated his greatest mathematical discoveries—Huygens focused on the problem of gravitational acceleration, recognizing that it was mathematically equivalent to centrifugal force. This insight led him to a theoretical justification for his clock's design that would form the nucleus of his most important book, the *Horologium oscillatorium* (1673).

By 1663, Huygens's fame had spread to England, where he was elected fellow of the Royal Society. Over the next decade, he worked on problems of collision and impact and attempted to adapt pendulum clocks for use on ships. Mounting pairs of sea clocks on the same frame led to his discovery of the property of coupled oscillation, since the pendulums tended to oscillate in exactly opposite directions. His explanation for this phenomenon as due to tiny movements in the frame ultimately led to the abandonment of his sea clock experiments organized by London's Royal Society, for it became clear that such clocks would be affected by a ship's movements. Huygens would later (1675) invent a balance spring clock (for which Robert Hooke also claimed priority), but his concern about the effects of humidity on its accuracy prevented him from intensely pursuing its use at sea.

In 1666, Huygens accepted Louis XIV's invitation to help found the French Academy of Sciences and moved to France. Although he had intended to prove his clock's maritime utility before publishing a detailed theoretical account, the *Horologium oscillatorium* went to press in 1673 with a dedication to the French king, probably for political reasons, as France was then at war with his native Holland. This treatise offered proofs of the relationship between the length of the pendulum and its period, of the center of oscillation of simple and compound pendulums, and further demonstrated that the bob of an isochronous pendulum follows a cycloid path and that a cycloid is its own evolute. Huygens concluded with a short disquisition on conical pendulums and centrifugal force. One of the last important examples of geometrical physics—physics that relies on word proofs involving geometrical figures and relations between physical quantities expressed as proportions—Huygens's style of analysis would soon be supplanted by mathematical physics, which uses equations of differential calculus invented by Isaac Newton and Gottfried Wilhelm Leibniz (with whom he was in regular contact). The book's diminished influence despite its important discoveries was partly due to its geometrical argumentation and infinitesimal analysis and partly due to its publication long after Huygens's initial discoveries.

The 1670's also produced research in physical optics: Huygens devised a wave, or pulse, theory of light and Huygens' principle (all points of a wavefront of light generate new wavelets in all directions), which he used to explain reflection and refraction. Although drafted by 1678, his *Traité de la Lumière* was not published until 1690. After he returned to The Hague in 1681 to recover from an illness, Huygens studied the problems of spherical and chromatic aberration, grinding lenses of great focal distance and creating aerial telescopes—telescopes that did not use tubes but rather a very long cord to line up the lenses. Because of the political climate, Huygens did not return to Paris, thereafter making his home in Holland, where he continued to study mathematics and optics and to tinker with clocks. On a final trip to England in 1689, he met Newton, who had recently published his *Principia* (1687). By early 1695, Huygens had finished a manuscript of his *Cosmotheoros* (1698), in which he posited life on other planets. Later that year, he died, leaving his papers to the University of Leiden.

IMPACT

Huygens's three main areas of inquiry and invention—telescope lenses, pendular mechanics, and physical optics—produced a variety of profound effects on scientific knowledge and contemporary society. Huygens's recognition of Saturn's rings not only gave scientists a more accurate picture of the solar system but also opened up a line of inquiry regarding the nature of those rings that is still being pursued today. His aerial telescopes constituted a first step toward creating the much stronger telescopes needed for precise astronomic observation (for which internal mirrors would eventually be substituted for distance between the lenses). The pendulum clock's far superior accuracy was not only fundamental to astronomical observation and scientific experimentation but also offered society a clock that was, for the first time, more accurate than a sundial, therefore encouraging the eventual adoption of mean time and equal hours as opposed to Sun time and unequal hours. The mathematical foundation for his cycloid pendulum and his proof that its evolute was also a cycloid led to further inquiries in differential geometry regarding the nature of other curves and their evolutes. Finally, although Huygens's wave theory of light was quickly challenged by Newton's particle theory, by the 1800's it was returning to favor when further studies by Augustin-Jean Fresnel and others supported his view. Eventually, both the wave and particle theories were brought together and broadened to cover all electromagnetic phenomena in what is called the wave-particle duality, a fundamental component of modern quantum mechanics.

—Maia Wellington Gahtan

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See also: Galileo; James Gregory; Robert Hooke; Zacharias Janssen; Hans Lippershey; Sir Isaac Newton; Blaise Pascal.

IDA H. HYDE

German American physiologist and zoologist

Hyde invented the microelectrode, an instrument small enough to be injected into a single cell. She received no recognition for her work during her lifetime.

Born: September 8, 1857; Davenport, Iowa
Died: August 22, 1945; Berkeley, California
Also known as: Ida Henrietta Hyde (full name)
Primary field: Medicine and medical technology
Primary invention: Microelectrode

EARLY LIFE

Ida Henrietta Hyde (I-dah Hehn-ree-EH-tah HID) was one of four children born to German immigrants Babette Loewenthal, a businesswoman, and Meyer Heidenheimer, a merchant. The Heidenheimers changed their family name to Hyde when they arrived in the United States. Mr. Hyde abandoned the family when Ida was still a child. Her mother supported them by doing mending and cleaning work. As a businesswoman, Mrs. Hyde was able to gradually develop her work into a fairly successful small business.

Sometime before 1870, the family moved to Chicago, but shortly thereafter the Great Chicago Fire destroyed their home and displaced their customers. Ida Hyde took an apprenticeship at a hatmaking factory and worked there for seven years to help support the family and to fund her brother's education. One day, she happened to pick up a discarded biology book from a packing crate. It was Alexander von Humboldt's *Views of Nature* (1850; *Ansichten der Natur*, 1808). At her brother's graduation ceremony from the University of Illinois, she met female students and had the idea that perhaps she could also be a student. Neither her mother nor her brother approved of her taking classes, but she was determined and in 1881 easily passed the entrance examination. She walked to school and saved her unspent car fare to pay college tuition for night classes at the university. When her brother became ill in 1882, she suspended her classes to care for him at home, where she stayed for six more years, teaching first in Elmhurst, a suburb of Chicago, and then in the Chicago public system, where she instructed seven- and eight-year-olds. During the summer of 1882, she attended Summer School of Natural History in Martha's Vineyard. During these years, she compiled a systemwide science curriculum for the Chicago public schools.

LIFE'S WORK

In 1888, Hyde enrolled at Cornell University and in three years completed a bachelor of arts in biological science. As part of her studies, she carried out an outstanding undergraduate research project on mammalian heart structure that was reported in the *American Naturalist* in 1891. During the summer, she worked for Woods Hole Marine Laboratory Corporation in Maine—the first woman to do so—where she analyzed octopus embryos, jellyfish development, and the respiration of grasshoppers, horseshoe crabs, skates, amphibians, and mammals. In 1892, she lectured on the anatomy and embryology of Scyphomedusae, the class of sea animals composed of jellyfish and other gelatinous organisms.

Impressed with her work in this area, Professor Alexander Goette invited Hyde to conduct further research at the University of Strasbourg in France. Goette was so impressed that he offered her reports to the academic committee in lieu of a doctoral dissertation. However, solely on the basis of her gender, the academic staff rejected her petition to take final exams. Goette then recommended that she apply at the University of Heidelberg in Germany.

The university accepted her, but again she had to overcome obstacles. Dr. Wilhelm Kühne, a noted researcher who coined the word “enzyme,” refused to allow her in lectures and laboratories. (Reportedly, he had said that he would never allow “skirts” in his classes.) However, when a colleague asked him whether, if at the end of the course she could pass the examination, he would grant her the degree, he jokingly replied that he would. For six semesters, Hyde had to study physiology independent of the classroom and of hands-on laboratory projects, relying only on Kühne’s assistants’ notes and lab sketches. Finally, a four-hour oral examination by Kühne’s academic committee proved her worthiness. The summa cum laude degree, the highest honors, could not go to a woman, so Kühne invented a new phrase: “multa cum laude superavit” (she overcame with much praise).

THE MICROELECTRODE

Even as a teenager and young adult, Ida H. Hyde had been interested in scientific research. As an undergraduate student at Cornell University in 1891, she published her first research paper, “Notes on the Hearts of Certain Mammals.” At Woods Hole Marine Laboratory Corporation, she analyzed octopus embryos, jellyfish development, and the respiration of grasshoppers, horseshoe crabs, skates, amphibians, and mammals. While at the University of Kansas, she continued her study of the response of the cardiovascular system to stress. Toward the end of her time at the university, by chance she observed that electrolytes in high concentrations affect processes of cell division, and this led her to note minute differences in electrical potential within cells.

During the years 1918-1919, Hyde worked on single-celled organisms and the eggs of sea urchins. However, in order to understand how nerve and muscle cells work, she needed to be able to stimulate individual cells electrically or chemically and to record the resulting changes in the very small electric current that the cell produces. Hyde needed to be able to stimulate the cell by injecting an electric current and at the same time record the changes that took place. There were instruments that did this, but none of them were small enough to fit into a single cell, so she constructed an instrument called the microelectrode, which had a diameter small enough for her purpose. Using this instrument, Hyde was able to prove that a previously held principle, the “all-or-nothing” principle concerning contractile cells, did not always hold true. She was able to show that a certain single-celled organism did not follow the pattern, thus disproving the all-or-nothing principle.

Although Hyde’s invention was reported in 1921, Georg Ettisch and Tibor Péterfi, apparently unaware of it, manufactured an electrode that was essentially the same as Hyde’s. It was again reinvented twenty years later by Judith Graham and Ralph W. Gerard of the University of Chicago, apparently with no knowledge of Hyde’s earlier work. In the 1950’s, Gerard was nominated for a Nobel Prize for developing still another version of the microelectrode. Science historian G. Kass-Simon has praised Hyde’s invention as the “most useful and powerful tool in electrophysiology. Its invention revolutionized neurophysiology.”

In 1896, Hyde completed the Ph.D. at Heidelberg, the first woman to receive one for this type of work, opening the way for other women to do the same. Kühne recommended her for a position in a research program at the Naples Marine Biological Laboratory in Italy, where she studied the nature and function of salivary glands. Years later, Hyde convinced a group of university women to fund a permanent visiting professorship for women at the Naples Marine Biological Laboratory. She was a life member of this organization and its secretary from 1897 to 1900.

In 1898, Hyde joined the staff at the University of Kansas. In 1903, the school created a separate physiology department with Hyde as its head. There she developed a new curriculum and wrote two textbooks: *Outlines of Experimental Physiology* (1905) and *Laboratory Outlines of Physiology* (1910). She continued to write articles on developing embryos and microtechniques of cell study. As a result, in 1902 she was the first woman elected to the all-male American Physiological Society. She was the only woman until 1913 whose original contributions were considered to meet the society standards for membership.

During her time in Kansas, Hyde again experienced gender discrimination. She pressed repeatedly for a salary that was equal to her male colleagues’. She added restroom facilities for women in the science building, she agitated and got women janitors hired by the university, and she started a drive to hire female corrections' officers in the city of Lawrence. She promoted educational opportunities for women by helping to establish the Sarah Robinson Research Table at Woods Hole.

Hyde taught classes on hygiene, public health, human reproduction, and sexually transmitted diseases. However, to avoid shocking her class, she read lines of poetry to refer to human and animal reproduction and relied on nude Greek and Roman statues rather than more detailed drawings of the human body. She educated Kansans on promiscuous sex and disease, taught classroom lessons on gonorrhea and syphilis for factory women, and teamed with medical doctors to prevent spinal meningitis and tuberculosis. She wanted to test schoolchildren for these diseases, but conservative opposition forced the university chancellor, Francis Strong, to withdraw his support, saying that "compulsory medicine" was not acceptable. In 1918, Governor Arthur Capper named Hyde chair of the Kansas Women's Committee on Health, Sanitation and National Defense. At the same time, President Woodrow Wilson selected her to chair the U.S. Women's Commission on Health and Sanitation.

In 1922-1923, Hyde took a last trip to Europe. She died on August 22, 1945, from a cerebral hemorrhage at her home in Berkeley, California. Her diaries are at the American Association of University Women (AAUW) archives in Washington, D.C. Information can also be found at the University of Kansas archives.

IMPACT

Hyde was the first woman to conduct research at the Woods Hole Marine Laboratory Corporation in Maine, and she was the first woman to attain a doctoral degree in physiology from the University of Heidelberg. She was the first female head of a Department of Physiology at the University of Kansas. Her most impressive accomplishment, for which she received no credit during her lifetime, was the invention of the microelectrode. Devices that added chemicals to a cell or recorded its current had been created earlier, but Hyde in 1920 was the first to make a tool that could do both at once and that was small enough to stimulate a single cell.

Hyde paved the way for other female scientists. With her own money, she funded scholarships at Cornell University, established the Ida H. Hyde Scholarship for the Biological Sciences at the University of Kansas, and endowed the Ida H. Hyde Woman's International Fellowship of the American Association of University Women with $25,000. She also gave $2,000 to the University of Kansas to fund a scholarship for female graduates in biology. She not only taught, conducted research, and wrote textbooks but also was interested in public health, teaching classes for the general public. She realized, before it was popular, the importance of testing schoolchildren for contagious diseases.

—*Winifred Whelan*

FURTHER READING

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Creese, Mary R. S. *Ladies in the Laboratory? American and British Women in Science, 1800-1900: A Survey of Their Contributions to Research*. Lanham, Md.: Scarecrow Press, 1998. In chapter 6, Creese compares female medical scientists from Britain and the United States. Of those from the United States, Hyde was one of the greatest contributors. Hyde's writings are listed, and a summary of her life is included.

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See also: Willem Einthoven; Robert Jarvik; Mary-Claire King.

SUMIO IIJIMA

Japanese physicist

Iijima's 1991 observation of multiwalled carbon nanotubes and his 1993 discovery of single-walled carbon nanotubes sparked intense research into these ultramicroscopic carbon needles, whose great strength and unique electrical behavior make them potential building blocks for far-reaching nanotechnological applications.

Born: May 2, 1939; Saitama Prefecture, Japan
Primary field: Physics
Primary invention: Single-walled carbon nanotubes

EARLY LIFE

Sumio Iijima (soo-mee-oh ee-ee-jee-mah) was born on May 2, 1939, in Saitama Prefecture in Japan, to the north of Tokyo. His father, Fukumatsu, and his mother, Take, brought up the boy in what was still a rural environment. Iijima loved mountain climbing so much that he focused less on his studies, even though chemistry and physics were favorite high school subjects. At age nineteen, in 1958, Iijima surprisingly failed the all-important national university entrance exams.

For the first time, Iijima took his studies seriously, and he prepared to retake the entrance exams the following year. In 1959, he passed and was admitted to the College of Electro-Communications in Chōfu, a city within greater Tokyo; his alma mater later became a university. After graduating with a bachelor of science degree in 1963, Iijima began graduate studies at Tohoku University in Sendai, northeastern Japan, which enjoyed an excellent reputation for technical studies. Even though his interest was originally in chemistry, Iijima was placed in the high-resolution electron microscopy laboratory and quickly earned a reputation as a very gifted microscopist.

At Tohoku University, Iijima earned his master of science degree in physics in 1965 and his doctorate in solid-state physics in 1968. On March 10, 1968, at age twenty-eight, Iijima married Aida Nobuko. The couple had two children, daughter Masako and son Arihiro.

LIFE'S WORK

At first, Iijima stayed at Tohoku University as a research associate. In 1970, he joined the high-resolution transmission electron microscopy (HRTEM) team of Professor John Cowley at Arizona State University (ASU) in Tempe as a visiting research associate. Iijima quickly developed a new technique for producing high-resolution electron micrographs of crystals. In 1971, he became the first scientist whose micrographs showed the atomic structure of certain crystals.

At ASU's Center for Solid State Science, which brought together microscopists from many disciplines, Iijima became known as the best microscopist. He was the first to capture microscopic images that showed the location of atomic defects within a crystal. His colleagues praised him for his unprecedented skill in sensing exactly where to aim the HRTEM instrument. He took the most promising pictures of what later became known as nanomaterials, ultrasmall pieces of matter impossible to see without a powerful electron microscope.

In 1973, Iijima began working for geologist Peter Buseck as a postdoctoral researcher at ASU. In 1974, Iijima formally resigned from Tohoku University to concentrate on his work at ASU. By 1976, Iijima and Buseck had published together seven breakthrough papers on electron microscopy of minerals. In 1977, Iijima became a senior research associate at ASU, a position he held until 1982.

Returning to Japan, from 1982 to 1987, Iijima was group leader and research scientist at the Exploratory Research for Advanced Technology (ERATO) of the Research Development Corporation of Japan. On December 11, 1984, he released a video, *Living Gold Crystals*, that showed his micrograph images of coalescing gold particles and real-life images of the motion of surface atoms on gold particles. No other scientist had looked so deep into the atomic structure of gold before.

In 1987, Iijima joined NEC Corporation in Japan, where he has remained as a senior research fellow. It was at NEC's Fundamental Research Laboratories in Tsukuba that Iijima made his most outstanding discovery. Since their detection in 1985, carbon-60 molecules, also called fullerenes, were the focus of the emerging field of nanoscience. Iijima was less interested in the fullerenes themselves than in the way in which they formed in the sooty carbon remains after electricity passed through two carbon electrodes and vaporized them. In the summer of 1991, utilizing a standard transmission electron microscope, Iijima looked at the tip of the negative carbon electrode after he had brought it so close to the positive electrode that they were joined by an electric arc spark. To his surprise, Iijima could take microscope images of what he determined were multiwalled carbon nanotubes. Iijima's images showed twist-

Single-Walled Carbon Nanotubes

After Sumio Iijima's successful 1991 microscoping of multiwalled carbon nanotubes that revealed these microscopic graphite needles to the larger scientific community, Iijima and his colleague Toshinari Ichihashi turned to the idea of creating and observing single-walled carbon nanotubes. Iijima believed that only the observation of single-walled nanotubes would yield full scientific knowledge of the exact characteristics of these tiny structures with a diameter of just about one-billionth of a meter and a length of up to one thousand times their diameter.

The idea of the existence and possible artificial growth of these ultrasmall particles was mentioned first in a U.S. patent of 1889, but there were no technical means in existence then to prove this. Optical microscopes could never go as far into microscopic detail as was necessary to observe these nanostructures. Only with the invention of the transmission electron microscope in 1939 were scientists able to look into the nanoscale realm with gradually increasing power of observation. Unbeknownst in the West during the Cold War, in 1952 two Soviet physicists, L. V. Radushkevich and V. M. Lukyanovich, published micrograph images that they had taken of carbon filaments. In 2006, when these old photos were examined again, it became clear that they actually showed multiwalled carbon nanotubes, making Radushkevich and Lukyanovich the first to discover them. Still, it was Iijima's 1991 observation of multiwalled carbon nanotubes that triggered the great interest in these structures. Moreover, the quest was still open for the discovery of a single-walled carbon nanotube.

To this end, Iijima and Ichihashi decided on a new approach to grow carbon nanotubes, which so far had been observed only in their multiwalled state. In 1993, Iijima set up an experiment at his Fundamental Research Laboratories of the NEC Corporation in Tsukuba, Japan. In an evaporation chamber in their laboratory, two electrodes were set up in a vertical position close to each other. The anode consisted of a graphitic carbon rod with a diameter of 10 millimeters, while the graphitic carbon rod of the cathode had a diameter of 20 millimeters and held a small piece of iron in a hollow at its tip, acting as catalyst. The evaporation chamber was filled with a gas mixture of methane (a source of more carbon) and argon. Next, Iijima and Ichihashi applied a direct current of 200 amperes and 20 volts to run between the two electrodes, creating a carbon discharge arc that vaporized the iron and the carbon, which formed soot together with the methane. The resulting soot that collected over the electrodes was put into an acetone suspension and placed under Iijima's microscopes.

Looking at the carbon soot with both a regular and an ultrahigh-vacuum transmission electron microscope, Iijima took the image of the single-walled carbon nanotubes that the experiment had generated. The discovery of these nanotubes, with diameters from 0.7 to 1.6 nanometers each, triggered further advances in the research of their exact mechanic and electric properties. Iijima and Ichihashi had discovered the basis on which the new field of nanotechnology came to be built.

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ing carbon tubes consisting of multiple cylinders. The smallest, innermost cylinders had a diameter of four nanometers, and the largest cylinders forming the outer shell of the multiwalled tube had a diameter of thirty nanometers. (Nanoscale objects are extremely small; one nanometer is equal to one-billionth of a meter, or 3.28 billionths of a foot.) The length of the twisting nanotubes reached up to one micrometer, or 1,000 nanometers.

Describing his findings in the November 6, 1991, issue of *Nature* magazine, Iijima electrified the nanoscience community. On April 23, 1993, Iijima and his colleague Toshinari Ichihashi submitted to *Nature* their paper showing their discovery of single-walled carbon nanotubes. Iijima and Ichihashi successfully grew and then took microscope pictures of carbon nanotubes consisting of only one cylinder. These two papers laid the much-cited foundation for carbon nanotube research.

Having already won five major physics awards for his microscopy discoveries, in 1996 Iijima received the Asahi Award of the Asahi Shinbun Cultural Foundation of Japan, the first science award of many to follow for his discovery of single-walled carbon nanotubes. Iijima continued his microscopic research of carbon nanotubes to discover more about their structure, properties, and potential applications, and in 1998 he was appointed professor in the Department of Materials Science and Engineering of Meijo University in Nagoya, Japan, a position he has since held. After discovering a special form of curved, conical carbon tubes he called nanohorns, in 1998 Iijima became research director of the Nanotubulites Project of the Japan Science and Technology Agency, a position he held until 2002.

Iijima's great status in the avant-garde field of nanoscience was reflected by his ongoing scientific appointments and scientific awards. On April 1, 2001, he became founding director of the Nanotube Research Center of the National Institute of Advanced Industrial Science and Technology, a position he has since held. His receiving the Benjamin Franklin Medal in Physics in 2002 was a special honor. In 2005, Iijima became dean of Sungkyunkwan University's Advanced Institute of Nanotechnology (SAINT) in South Korea. He was named honorary professor of Xi'an Jiaotong University in 2005 and of Peking University in 2006.

On May 28, 2008, the Norwegian Academy of Science and Letters together with the Kavli Foundation of Oxnard, California, announced that Iijima was co-awarded with Louis Brus from Columbia University the first Kavli Prize in Nanoscience. Iijima and Brus shared the one-million-dollar prize for their discoveries in the fields of carbon nanotubes and colloidal semiconductor nanocrystals, commonly called quantum dots. By 2009, at age seventy, Iijima continued his research and hoped for more discoveries in nanoscience.

Impact

Iijima's two papers published in *Nature* in 1991 and 1993 were generally credited with ushering in the era of carbon nanotube research, fueling research in nanoscience and nanotechnology in general. Iijima published his findings at the right time to send scientists on the quest for new nanomaterials. Carbon nanotubes as popularized by Iijima hold great potential applications because of their great strength and flexibility. Even if bent out of shape, they quickly flex back into their original state, making them potentially ideal for auto body parts, for example. Their electrical properties can be metallic (fully conducting), semiconducting, or superconducting, making them suitable for new applications in electrical engineering and computer science.

On the basis of Iijima's fundamental research, which included an impressive body of discoveries in nanoscience, other researchers pursued a great variety of practical nanotechnological applications. Ultrathin nanotube wires could revolutionize the computer chip industry by offering nanotechnological transistors. Already in use by 2009 were applications in microscopy. Attaching a nanotube to the tip of a scanning microscope creates better resolution and lets the probe delve deeper into material. Carbon nanotubes were already being used in composites for industrial fibers and stain-free textiles.

By 2009, scientists still searched for new revolutionary carbon nanotube applications such as superstrong fibers, vastly powerful yet small fuel cells, and nanotube computer circuits. However, by 2008, there were new concerns about the possible toxicity of carbon nanotubes rivaling that of asbestos needles. This meant more research was needed to study this potentially harmful side effect.

—*R. C. Lutz*

Further Reading

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See also: Gerd Binnig; Heinrich Rohrer.

KARL G. JANSKY

American physicist, astronomer, and engineer

Jansky is considered by many to be the "father of radio astronomy." While working to reduce radio interference, he discovered the first astronomical radio emissions. In his honor, radio astronomers measure the intensity of celestial radio emissions in units called janskys.

Born: October 22, 1905; Norman, Oklahoma
Died: February 14, 1950; Red Bank, New Jersey
Also known as: Karl Guthe Jansky (full name)
Primary fields: Astronomy; physics
Primary invention: Radio astronomy

EARLY LIFE

Karl Guthe Jansky (kahrl gewth JAN-skee) was born on October 22, 1905, in Norman, Oklahoma, which at the time was a territory rather than a state. His father, Cyril M. Jansky, was a professor and dean of the College of Engineering at the University of Oklahoma. His mother, Nellie Moreau Jansky, was of French and English descent, while his father was the son of Czech immigrants. Karl Jansky was named for physicist Karl Guthe, who was an admired teacher and coworker of Cyril. In 1908, the Jansky family moved to Madison, Wisconsin, when Cyril accepted a position at the University of Wisconsin. Jansky attended Wisconsin public schools and later the University of Wisconsin.

Jansky graduated with a B.S. in physics from the University of Wisconsin in 1927. He was an excellent student, a member of Phi Beta Kappa, and graduated with honors. While in college, his extracurricular activities included playing on the college ice hockey team and playing tennis for recreation. After receiving his bachelor's degree, Jansky stayed an extra year to complete the coursework for his master's degree, but he did not graduate with the degree in 1928 because he had not completed the thesis requirement. The university finally awarded Jansky a master's degree in 1936, when it counted his early work in radio astronomy for his thesis requirement.

While still a college student, Jansky was diagnosed with chronic kidney disease. This affected his life by limiting the types of work he could do; his job assignments could not unduly stress his health. In addition, his illness limited the length of his life: He died when he was only forty-four years old.

LIFE'S WORK

In 1928, Jansky went to work for Bell Labs in New Jersey. He almost did not get the job because of his health. However, one of his brothers, who was ten years older and had previously worked for Bell Labs, intervened on his behalf. Jansky's first assignment at Bell Labs was of a purely applied nature. Bell Labs had a strong interest in radio telecommunications, which requires transmitters and receivers having the lowest possible amount of static or noise. Bell Labs assigned Jansky to work at its Cliffwood, New Jersey, field laboratory. Using and modifying existing equipment, Jansky began to study the static at 14.6-meter radio wavelengths (20.5 megahertz), which is in the shortwave band. In 1930, Bell Labs moved the entire Cliffwood laboratory to Holmdel, New Jersey. The move interrupted Jansky's work, but he rebuilt his rotating antenna and receiving equipment in Holmdel. The fact that Jansky's antenna rotated like a merry-go-round allowed him to study the direction of origin of any radio static he received.

This project required considerable work to design and modify the receiving equipment. By late 1930, Jansky had begun to study the 14-meter wavelength radio static in detail. He began to carefully and laboriously record data on the strength of the radio static in different directions and at different times. Jansky's data showed three sources of radio static: distant and local thunderstorms and a third unidentified source. Jansky published his work, entitled "Directional Studies of Atmospherics at High Frequencies," in late 1932 in the *Proceedings of the Institute of Radio Engineers*. Jansky further investigated this third unknown source of static and concluded from its direction of origin that the radio waves did not originate anywhere on Earth or in the solar system. The signal strength varied with a cycle time equal to Earth's rotational period, which is characteristic of signals originating from outside the solar system. Jansky discussed his work with A. M. Skellet, a coworker who was familiar with astronomy, and they concluded that the source was the Milky Way galaxy. Jansky published his work in the fall, 1933, issues of *Proceedings of the Institute of Radio Engineers* and *Nature*. The papers were titled "Electrical Disturbances Apparently of Extraterrestrial Origin" and "Radio Waves From Outside the Solar System," respectively. These classic papers by Jansky form the foundation of modern radio astronomy. The May 5, 1933, issue of *The New York Times* featured a story about Jansky's work.

After his initial discovery, Jansky suggested that Bell Labs fund the building of a larger, more sensitive antenna. The research organization, however, declined his proposal because it would not have addressed the feasibility of radio telecommunications. Jansky continued to observe the radio static from the Milky Way until 1936 and confirmed his conclusion that the center of the Milky Way galaxy was indeed the source of the radio noise. He published a summary of his results on astronomical radio static in a paper titled "Minimum Noise Levels Obtained on Short-Wave Receiving Systems" in the *Proceedings of the Institute of Radio Engineers* in December, 1937. Having received no encouragement from the astronomical community, Jansky shortly thereafter stopped studying these astronomical radio signals. The astronomical community of the time did not recognize the potential importance of radio astronomy.

Jansky continued to work on applied aspects of radio noise. He performed experimental studies of radio noise and measured the angle at which transatlantic radio signals arrived. In 1940, he also compared possible sites for receiving these signals. When World War II broke out, Bell Labs went into defense-related research, and employees worked overtime on war-related projects such as radar. There was no time for Jansky to pursue radio astronomy. Jansky, like most American scientists and engineers of the era, contributed to the war effort. He did not publish the results of this defense work because it was classified.

After the war, Bell Labs started to concentrate on the possibility of using microwaves, rather than the shortwaves Jansky had previously studied, for communications. Jansky contributed to this work by designing receivers and amplifiers with minimum noise levels. He even started experimenting with transistors, which had recently been invented, in the amplifiers. However, Jansky's chronic kidney disease was worsening, and he was forced to take an extended sick leave in 1945-1946. During 1948, he traveled more than once to Duke University Medical Center in Durham, North Carolina, for treatment. Jansky's health continued to deteriorate, and he died on February 14, 1950.

RADIO ASTRONOMY

Most people are familiar with optical astronomy, a subfield that deals with light from stars, planets, galaxies, and other celestial objects. Fewer people are familiar with radio astronomy, which involves the use of large radio antennae to study radio waves coming from a variety of celestial objects. Much of the current knowledge of the universe comes from radio astronomy. As the first person to discover and study radio waves from celestial objects, Karl G. Jansky is rightly considered the "father of radio astronomy."

Large optical telescopes use a large concave mirror, usually combined with a smaller secondary mirror, to reflect the light to a focal point for detailed study. Similarly, radio telescopes use a large concave metal surface to reflect radio waves to a focal point for further study. This reflecting surface resembles the reflecting surface of a receiver for satellite TV signals, but it is much larger. Just as a satellite TV receiver points in a specific direction of the sky containing a satellite, so too a radio telescope points in a specific direction of the sky to locate the source of extraterrestrial radio waves. This directionality allows astronomers to know which celestial object is transmitting the radio signals being studied.

At the focal point of the radio reflector, astronomers place a receiver and amplifier to study the radio signal. The receivers are tunable, so astronomers can study the frequency dependence of radio waves emitted by various celestial objects. Radio astronomers can map an area of the sky at any radio frequency or study a celestial object's signal strength, which varies with the frequency.

Radio waves are not as easily absorbed by interstellar dust as visible light. Therefore, radio astronomy is very useful for studying celestial objects that would normally be obscured by interstellar dust. Though ordinary stars are not very bright at radio wavelengths, other types of celestial objects are. These objects include pulsars, quasars, the core of the Milky Way, and most active galaxies. Radio astronomy has been crucial for understanding these objects and many more.

IMPACT

Professional astronomers initially ignored Jansky's seminal work on radio astronomy. In the 1930's, astronomers did not think there was much to learn by studying radio waves from space, and during the Great Depression it was difficult to justify the expense of radio telescopes. There were, however, two people who directly built on Jansky's work, Grote Reber and John Kraus. Reber, a ham radio operator and amateur astronomer, built a radio telescope in his backyard in 1937. Reber used about a half year's pay to build his first radio telescope, using it to map the radio sky. Kraus was the first professional astronomer to build on Jansky's work. After World War II, Kraus founded the radio observatory at Ohio State University. After Reber and Kraus demonstrated that it was worth studying celestial radio sources, professional astronomers started doing radio astronomy.

Thanks to Jansky's pioneering discovery, radio astronomy is now a very important branch of observational astronomy. Pulsars and quasars are two of many good examples of unsuspected new types of celestial phenomena that were discovered by radio astronomy. In honor of Jansky's contribution to the development of radio astronomy, astronomers measure the intensity of radio and infrared signals from celestial bodies in units called janskys. One jansky is defined as 10^{-26} watts/meter^2 hertz.

Because he died before radio astronomy became an important subfield, Jansky received few honors in his lifetime. He was made a fellow of the Institute of Radio Engineers in 1948. Some have speculated that if he had lived to see the important discoveries made by radio astronomy, he might have won the Nobel Prize for his seminal work in that subfield.

—*Paul A. Heckert*

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See also: George Edward Alcorn; Heinrich Hertz; Guglielmo Marconi.

ZACHARIAS JANSSEN

Dutch lens maker

Janssen was a Dutch optician with a claim to having invented both the telescope and the microscope. With improvements by scientists such as Galileo, Cornelius Drebbel, and Antoni van Leeuwenhoek, the telescope and microscope soon became the most important scientific instruments in astronomy and biology.

Born: c. 1580; The Hague, the Netherlands
Died: c. 1638; Amsterdam, the Netherlands
Also known as: Sacharias Jansen
Primary field: Optics
Primary inventions: Compound microscope; telescope

EARLY LIFE

Zacharias Janssen (zak-a-RI-ehs YAHN-sehn) was born in the Netherlands around 1580, although his birth has been variously placed in the years 1580 to 1590. Holland was besieged by Spain during this period, and in the 1580's Janssen's family fled to Middelburg, located in the Dutch province of Zeeland. His father, Johannes (Hans), was a skilled optician and owned a spectacles shop in Middelburg. Johannes, perhaps with the assistance of Zacharias, experimented fruitfully with the magnification of spectacle lenses. After the death of Johannes around 1592, Zacharias inherited his father's optical shop. He also peddled his optical goods at town fairs and markets. Zacharias was a childhood friend and neighbor of William Boreel, whose father was a director of the Dutch mint; Zacharias apparently observed enough that he could later become a counterfeiter. On November 6, 1610, Zacharias married Catharina de Haene. Their son, Johannes Sachariassen, was born the following September.

LIFE'S WORK

Janssen engaged in two moneymaking ventures in addition to his work as a lens crafter. The first was the making of a telescope and microscope, which would give his name historic recognition; the second was counterfeiting, which would jeopardize his life. The scientific instruments developed from his lens-crafting trade while he was young; his career as a counterfeiter started later.

The precise details of the invention of the telescope and the microscope cannot be definitively ascertained. There were precursors of the telescope in Italy in the 1590's before the first real telescopes appeared in Holland in the 1600's. At least three Dutch lens makers have claims to the invention of the telescope—Janssen, Hans Lippershey, and Jacob Metius. Historians such as Cornelis de Waard and Albert Van Helden have described a scenario crediting Janssen as the first inventor based on circumstantial evidence and informed speculation.

The invention of the telescope resulted from the expertise of Dutch opticians in crafting spectacle lenses. Convex eyeglasses were invented in late thirteenth century Italy to assist elderly people suffering from presbyopia. Concave lenses were invented later for myopia. A convex lens is thick in the middle and curves outward; a concave lens is thinner in the middle and curves inward; a planar lens is flat. The angle of the lens determines the refraction of light and thus the magnification. In the fifteenth and sixteenth centuries, lens-grinding techniques and the quality of glass for both convex and concave lenses steadily improved. As part of his explorations in magnification in the beginning of the seventeenth century, Janssen probably put a stronger concave lens against his eye and a weaker convex lens some distance apart. When he looked through the two lenses, he saw distant objects magnified. Connecting the two lenses with a tube, Janssen was able to make the first telescope, probably in the year 1604. It is also possible that Janssen had heard about or seen a similar instrument that had been made in Italy several years before, perhaps as early as 1590. Because this telescope employed glass lenses to refract light, it would come to be called a refracting telescope. Because an obvious use was for the military to spot enemy forces on land and sea, the telescope was first known as a spyglass.

Over the next few years, Janssen may have worked secretly to increase the magnification of the spyglass, to about three times. Historians believe that Janssen's character was such that when his spyglass had reached a sufficient magnification, he would try to quickly profit from his invention rather than undertake the legal machinations of obtaining a patent. In September of

THE COMPOUND MICROSCOPE

The first telescopes invented by Zacharias Janssen, Hans Lippershey, and other Dutch opticians in the first decade of the seventeenth century developed directly from their experiences as lens makers. These opticians connected a strong concave lens eyepiece with a weaker convex objective lens. The objective lens and eyepiece work in concert in focusing and magnifying the light from the object. The convex objective lens collects and focuses light from the distant object, and the concave eyepiece lens makes the light rays parallel as they enter the human eye. As a result, distant objects and panoramas are made to appear closer with an increase in size, definition, and brightness. The magnifying power is proportional to the ratio of the focal length of the objective to the focal length of the eyepiece. When Galileo heard of the Dutch discovery, he began making his own refracting telescopes and microscopes in May, 1609. His improved telescopes were soon capable of a magnification of thirty-six times, by which he was quickly able to discover the mountainous surface of Earth's moon, the four moons of Jupiter, the phases of Venus, sunspots, and the stars of the Milky Way. In the following decades, Johannes Kepler, Christiaan Huygens, Isaac Newton, James Gregory, and Guillaume Cassegrain introduced new forms of optical telescopes, including the "reflecting" telescope, which utilizes curved mirrors. By the middle of the seventeenth century, refracting and reflecting telescopes were able to magnify objects one hundred times. In later centuries, radio and other telescopes were developed that reach distant galaxies.

Janssen is usually credited with the invention of the compound microscope. Janssen's microscope, like his telescope, worked by refraction—that is, the bending of light rays. The objective lens collects the image of the miniature object, which is further magnified by the eyepiece. In the Middelburg Museum, there is a primitive compound microscope that was donated in 1866 and may well be one of Janssen's original microscopes. It resembles a telescope and consists of two cylindrical tubes held together by a third tube that acts as a sleeve and enables the microscope to be handheld. At one end is a plano-convex objective lens and at the other the biconvex eyepiece. This microscope could magnify objects up to nine times. Antoni van Leeuwenhoek's sophisticated single-lens microscopes in the 1670's magnified objects 270 times and allowed him to make detailed observations and recordings of microscopic life. As with the optical telescope, the optical microscope has been surpassed. Electron microscopes invented in 1933 are essential to atomic physics.

1608, he was trying to sell a telescope at the Frankfurt Fair among his other optical wares, although a potential customer complained that the glass was cracked and the instrument too expensive. A few weeks later, on October 2, 1608, a neighboring spectacles maker, Hans Lippershey, petitioned the Dutch States-General in The Hague, the governing body of the Dutch Republic, for a patent for a binocular telescope. This patent application was denied because the investigating committee discovered that the art of making a spyglass telescope was already known to a young man. This young man was probably Janssen. Janssen, learning of Lippershey's application, may have gone to The Hague to present himself as the first inventor. Although denied a patent, Lippershey was commissioned to make two more binocular instruments. A few weeks later, yet another Middelburg lens maker, Jacob Metius, applied for a patent for a spyglass and was also denied. One of these early spyglasses was presented to Prince Maurice of Nassau, the Dutch stadtholder, and several others were soon dispersed around Europe.

The best claims for the invention of the telescope by Lippershey or Metius are their documented patent applications; for the claim of Janssen, it is the testimony of his son, Johannes Sachariassen, and of his childhood friend, William Boreel. In 1655, Boreel, serving as Dutch envoy to France, testified that Janssen was the inventor of the telescope. Boreel also claimed that Janssen was the first inventor of the compound microscope. Like the refracting telescope, a compound microscope consists of two lenses: an eyepiece and an objective lens, which refract light to magnify the image. The invention of the compound microscope probably developed from that of the telescope, as they both follow the same principle, except that with the microscope the object is placed on the objective lens. Therefore, it is plausible that the same person who invented one quickly developed the other. It is even possible that the same instrument served as both a rudimentary telescope and microscope. Boreel claimed to have seen one of Janssen's original microscopes in 1619. He described it as a tube one and a half feet long and two inches in diameter. The viewer looked through the glass at the top down to the minute object resting on an ebony disc at the bottom of the tube.

After 1610, Janssen's questionable activities increased. He was in legal trouble for unpaid drinking bills and for assault. In 1613, he was arrested for counterfeiting, but on April 22 the municipal court of Middelburg merely fined him, probably because he was counterfeiting Spanish copper quarters. Relocating to the town of Arnemuiden, he advanced to the more profitable counterfeiting of gold and silver coins. In 1618, Janssen was sentenced to death for counterfeiting. He avoided the capital sentence by escaping to Middelburg. Janssen's wife died in 1624, and he married Anna Couget a year later. After failing to meet a loan obligation on May 1, 1628, he was bankrupt and his property was auctioned. He died about ten years later, probably in Amsterdam.

IMPACT

The details of the invention of the telescope and microscope are lost to history, but the impact of their invention is clear. The telescope and microscope were invented by skilled Middelburg lens grinders in their workaday shops, without a theoretical knowledge of optics. It was some of history's greatest scientists who used their theoretical knowledge to improve these instruments and make astounding discoveries.

Eyeglasses were invented in Renaissance Italy, giving rise to speculation about the possibility of magnification through the manipulation of glass lenses. By the beginning of the 1600's, the skill of Dutch opticians had reached the point where the discovery of a simple refracting telescope and compound microscope was likely. Janssen may have been the first to invent a telescope in the years 1604 to 1608, but it may well have been Hans Lippershey or even Jacob Metius, or all three simultaneously. Certainly it was Lippershey who recorded and publicized the invention by applying for a patent in October, 1608. Although the States-General denied Lippershey his patent, its examining committee brought the new discoveries to the attention of the Dutch and soon all of Europe. The princes of Europe conceived of the telescope as a spyglass to obtain advantages over military enemies and assist navigation. Galileo had another idea. Relying on his superior knowledge of the theory of optics and refraction, he made an improved telescope within a year of learning of the Dutch discovery and aimed it at the sky. A half century later, the Dutch lens grinder Antoni van Leeuwenhoek and the English scientist Robert Hooke made improved microscopes and observed bacteria swimming in drops of water.

By meticulous, unaided observation, astronomers such as Nicolaus Copernicus, Johann Bayer, and Tycho Brahe had plotted the solar system to a remarkable degree, but with the telescope, scientists such as Galileo, Johannes Kepler, and Isaac Newton were able to reveal the secrets of the planets, Sun, and stars, and of light and gravity that bind them. With the microscope, the fundamental life of microorganisms was revealed. From the commercial grinding and manipulation of lenses by opticians at the dawn of the Dutch Golden Age came the instruments that have transformed science.

—*Howard Bromberg*

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See also: Roger Bacon; Galileo; James Gregory; Robert Hooke; Christiaan Huygens; Antoni van Leeuwenhoek; Hans Lippershey; Sir Isaac Newton.

ROBERT JARVIK

American scientist and zoologist

Jarvik's work on artificial hearts resulted in the Jarvik-7, which kept terminally ill heart patients alive for as long as 620 days and encouraged other researchers in their quest to find permanent replacement hearts for the growing number of heart patients.

Born: May 11, 1946; Midland, Michigan
Also known as: Robert Koffler Jarvik (full name)
Primary field: Medicine and medical technology
Primary invention: Jarvik-7 artificial heart

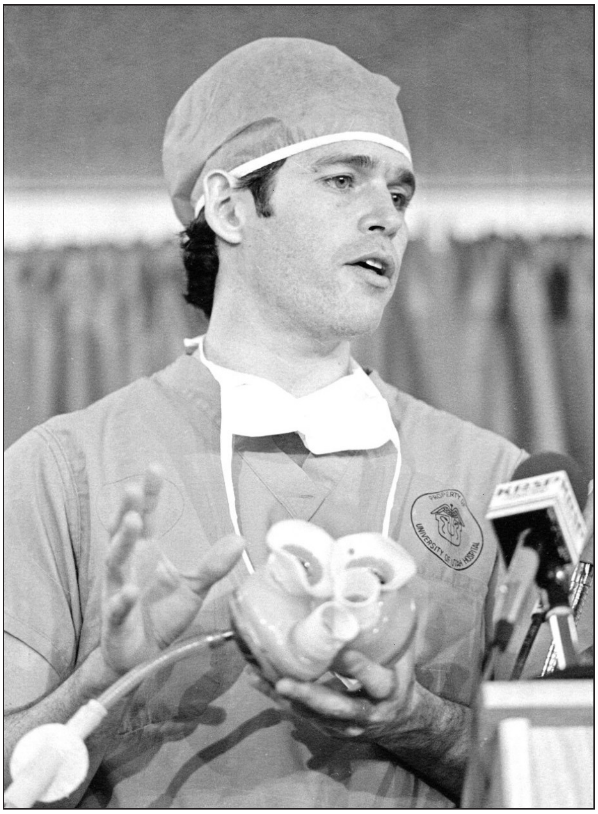
EARLY LIFE

Robert Koffler Jarvik was born in Midland, Michigan, but his parents (Norman Eugene Jarvik, a physician, and Edythe Koffler Jarvik) moved to Stamford, Connecticut, where his father became a prominent surgeon. In elementary school, young Jarvik built model airplanes and ships and displayed great manual dexterity. He said that he was always taking things apart and reassembling them in his mind. Before he graduated from high school, Jarvik, who often observed his father's operations, was interested in medicine, but he was even more concerned with building things and solving problems. His first invention, which he patented, was a time-saving automatic surgical stapling machine to replace the slow sewing by hand that was required to bind blood vessels together and to close wounds.

When he enrolled at Syracuse University in 1964, he was not intent on a medical career; but after studying different subjects without making real efforts, he chose zoology for a major. His change of major was caused by his father's near-fatal aortic aneurism. Jarvik then intended to enter medical school in order to solve heart problems. Unfortunately, the weak grades he received before deciding on a medical career prevented him from being accepted to American medical schools. As a result, he studied medicine at the University of Bologna for two years before returning to the United States to again apply to medical schools. When he was rejected again, he studied occupational biomechanics at New York University, where he received his master of arts degree in 1971. He was working at Ethicon, Inc., when his boss presented him with an opportunity to work, for a salary provided by the company, at the University of Utah's Institute for Biomedical Engineering and Division of Artificial Organs, headed by Dr. Willem Kolff. Because working at the institute would improve his chances for medical school admission, Jarvik applied for a job and was hired as a laboratory assistant in 1971.

Life's Work

Jarvik worked with Kolff, the man who had devised the first working artificial kidney and invented the world's first working kidney dialysis machine. Kolff then began work on creating artificial hearts. In 1957, he constructed an artificial heart that he implanted into a dog, which survived for ninety minutes. After he left the Cleveland, Ohio, clinic for the University of Utah, he began work on an artificial human heart, but progress was slow until Jarvik joined the team.



Robert Jarvik holds the Jarvik-7 artificial heart, which was first implanted in a patient in 1982. (AP/Wide World Photos)

At first, Jarvik worked on devising an artificial heart for a calf and improved on some of the designs of Dr. Clifford Kwan-Gett, a colleague at Utah. By substituting biomer, a Lycra-like elastic, for rubber, he was able to prevent the blood clotting that had caused the deaths of lab animals in earlier experiments. His Jarvik-3 artificial heart (designed in 1972) allowed the calf to live ninety days. He then turned his attention to an artificial human heart and was in competition with the work being done at the Baylor-Rice Artificial Heart Program in Houston, Texas. His Jarvik-7 was still another improvement, and it allowed a calf to live 268 days with the artificial heart in 1976, the same year he finished medical school and became an associate in Kolff's new company, Kolff Associates, later Kolff Medical, Inc. Three years later, he was a research assistant professor of surgery and biomedical engineering at the University of Utah School of Medicine.

Kolff's first request to implant an artificial heart into a human being was denied by the Food and Drug Administration (FDA) in 1979, but he got the necessary approval in 1981. The FDA approval, however, depended on the team using a class IV patient, someone over eighteen years of age who could not live after being taken off a heart-lung machine after open-heart surgery. Barney Clark was the patient, and Dr. William Castle DeVries implanted the Jarvik-7 in him in December, 1982. For his work, Jarvik was named "inventor of the year" by the Intellectual Property Owners Association in 1982 and by the National Inventors Hall of Fame in 1983. During the 1980's, he also received two honorary doctorates, one from his alma mater, Syracuse University, in 1983, and the other from the Hahnemann School of Medicine in 1985.

In the year before the Clark operation, Jarvik persuaded Kolff to name him president of Kolff Medical, Inc., which was renamed Symbion. The attractive, articulate Jarvik was a born fund-raiser, and with businessman W. Edward Massey he began to raise capital. The second operation (1984) was on William Schroeder, who survived for 620 days. Schroeder was the world's longest-surviving recipient of an artificial heart. Two other men died shortly after having Jarvik-7 implants. In 1987, the year Jarvik married Marilyn vos Savant, the brilliant "Ask Marilyn" columnist for *Parade* magazine, Symbion was acquired by a New York firm that subsequently fired Jarvik. The FDA shut the Jarvik-7 experiment down in 1990, and Jarvik moved to Houston, where he worked at the Texas Heart Institute and St. Luke's Episcopal Hospital. His next invention was the Jarvik 2000, a "bridge" between transplants that involves implanting a pump in the patient's left ventricle.

In 2006, Jarvik received a $1.35 million contract to become the television spokesperson for Pfizer's Lipitor, a best-selling drug used to lower cholesterol. His ads, which dramatically increased sales of the drug, came under fire because he wore a physician's uniform and was photographed rowing a boat. A double for Jarvik rowed the boat, and since Jarvik was never licensed to practice medicine (he never completed an internship or a residency, although he did complete medical school), his advice was construed as practicing without a license. Initially, Pfizer defended the ads, and Jarvik noted that he was a doctor and added that he was a medical scientist, not a practical doctor. Pfizer announced in February, 2008, that it was discontinuing the Jarvik ads.

IMPACT

Although Barney Clark's death was followed by others, none of whom lived more than William Schroeder's 620 days, and although the FDA rescinded its approval of the Jarvik-7 for human implantation in 1990, Jarvik's artificial heart spurred additional research in the use of artificial human hearts. The controversy surrounding the Jarvik-7 was responsible for bringing attention to the ethical, legal, and psychological issues involved in transplants and resulted in closer supervision of FDA approval procedures.

During the 1990's, Jarvik began developing the Jarvik 2000, a heart assist device that is placed in the patient's left ventricle, where its propeller pumps up to 1,500 gallons of blood daily. The device received FDA approval as a "bridge" between heart transplants. In 2006, researchers at Abiomed received FDA approval for their AbioCor replacement heart. Their artificial heart, made of plastic and titanium, is the size of a softball and weighs approximately three pounds. Unlike the Jarvik-7, it has an internal power source that allows it to work for up to thirty minutes. It also has power supplied by batteries that are attached to a belt. The improvements were made possible by the research inspired by Jarvik's work. Other medical advances in artificial hearts may ultimately save thousands of lives.

—*Thomas L. Erskine*

THE JARVIK-7 ARTIFICIAL HEART

The successor to the Jarvik-3 artificial heart was modeled after the human heart and is approximately the same size as a human's fist-sized heart. It weighs about ten ounces and is designed to replace the human heart. It has two artificial ventricles, which are like the pumping chambers of the heart and which replace the left and right ventricles, which the surgeon has removed. The device is made up of Dacron polyester, aluminum, and plastic. The patient's atria, the upper chambers of the heart that take in blood from the veins, is the anchor to which the Jarvik-7 heart is attached. The power for the device comes from an outside device that is connected to the patient's chest through tubes. As a result, the artificial heart duplicates the functioning of the human heart. The right atrium receives blood from the body, then pushes it down to the right ventricle, which pumps it to the lungs through pulmonary arteries to pick up oxygen. The oxygenated blood goes through the pulmonary arteries to the left atrium and is again pushed down, this time to the left ventricle through the mitral valve. The left ventricle then pumps the blood, after the mitral valve is closed and the aortic opened, to the rest of the body through the aorta. Essentially, the Jarvik-7 consists of the two ventricles, which comprise about two-thirds of the human heart.

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See also: Wilson Greatbatch; John Alexander Hopps; Willem Johan Kolff; Paul Winchell.

ALI JAVAN

Iranian American physicist

In 1960, Javan and his Bell Labs team built the first gas laser, the helium-neon laser. This invention, the first continuous-light laser, revolutionized telecommunications through fiber-optic technology and became widely used in UPC bar-code scanners, holography, and other applications.

Born: December 26, 1926; Tehran, Iran
Primary fields: Communications; physics
Primary invention: Helium-neon gas laser

EARLY LIFE

On December 26, 1926, Ali Javan (AH-lee JAH-von) was born in Tehran, Iran. His parents were Azarbaijanis from Tabriz, the largest city in northwestern Iran. His mother was an artist, and his father was a lawyer and writer interested in human rights. In early childhood, Javan became interested in science. At the age of five, he became fascinated with numbers and mathematics. He also enjoyed playing with gadgets, and at the age of seven Javan attempted his first invention, a camera made from a little box. He imagined many new gadgets that defied the laws of physics and could not possibly be built, but he experimented and tried to invent new devices.

Javan attended excellent schools, including the prestigious Alborz High School in Tehran. His schools had advanced mathematics and physics programs, and his teachers encouraged him to excel. He began studies at Tehran University, the largest university in the country, but in 1948 emigrated to the United States to continue his studies at Columbia University in New York. At Columbia, he studied physics and mathematics, and his doctoral adviser was Charles Hard Townes, who in 1953 invented the maser (microwave amplification by stimulated emission of radiation), the forerunner of the laser. The maser works by generating, focusing, and amplifying electromagnetic radiation, which is typically scattered and chaotic, into a stream that has more energy in the microwave portion of the electromagnetic spectrum. Javan studied microwave spectroscopy with Townes. Javan also took courses in the humanities and arts, such as music classes with the celebrated composer Henry Cowell.

LIFE'S WORK

In 1954, Javan received a Ph.D. in physics, but he stayed four more years as a postdoctoral student at Columbia University to work on masers and microwave spectroscopy. During this time, he had the idea for a three-level maser, but Bell Laboratories published its research first. The Radio Corporation of America (RCA) purchased the patent rights to the three-level maser from Javan and battled Bell for the patent. However, RCA decided that this maser was not feasible commercially and Bell could have the patent. In April, 1958, Bell Labs in Murray Hill, New Jersey, hired Javan to be part of their technical staff. In August, 1958, he began research on lasers.

The basic idea of the laser began in 1916 with Albert Einstein's view that atoms could release excess energy as light, either spontaneously or when stimulated by light. In 1917, the concept of stimulated emission appeared, and in 1928 physicist Rudolf Walther Ladenburg was the first to observe stimulated emission.

In 1953, Javan's thesis adviser Charles Hard Townes and associates J. P. Gordon and H. J. Zeiger built the first maser. Since masers had limited applications, Townes and Arthur L. Schawlow at Bell Labs discussed developing an optical maser that would involve the higher-frequency photons (rays of light, or electromagnetic energy moving in oscillating waves of various wavelengths) in the ultraviolet or visible light spectrum. Townes also discussed the subject with Gordon Gould, a graduate student at Columbia University. In the December 15, 1958, issue of *Physical Review*, Townes and Schawlow published a paper proposing an optical maser. In the meantime, Gould had coined the word "laser" (light amplification by stimulated emission of radiation) and applied for a patent. There followed a bitter thirty-year battle over patents and credit for the invention of the laser.

There was intense rivalry among research laboratories and scientists in the race to build the first laser. As 1960 began, no one had been able to build a working laser. Javan had conceived of a gas laser and had assembled a team at Bell Labs to develop a prototype. He had enlisted William R. Bennett, an experimental physicist and expert on gas discharges, and Donald R. Herriott, an optical specialist at Bell Labs, to help on this project. Javan had also published the idea in the *Physical Review Letters* in June, 1959.

On May 16, 1960, Theodore Harold Maiman of Hughes Research Laboratories in Malibu, California, demonstrated the first working laser, the ruby laser, which used a synthetic ruby crystal to produce short pulses of red light. On December 12, Javan, Bennett, and Herriott demonstrated the first gas laser, which generated a continuous infrared beam from a mixture of helium and neon. The next day, Javan's team was able to demonstrate the first telephone conversation transmitted by a laser beam.

In 1961, Javan became an associate professor of physics at the Massachusetts Institute of Technology (MIT), and he became a full professor in 1964. At MIT, he established the preeminent university laser laboratory of the 1960's and 1970's. The research here included significant developments in laser spectroscopy, atomic clocks, the use of lasers to test the special theory of relativity, and other scientific laser applications.

In recognition of his contributions to science, Javan received many honors and awards. These include the Stewart Ballentine Medal of the Franklin Institute (1964), the Fanny and John Hertz Foundation Medal (1966), a Guggenheim Fellowship (1966), and Humboldt Foundation Fellowships (1979 and 1995). In 1975, the Optical Society of America awarded Javan its most prestigious honor, the Fredric Ives Medal, which recognized the significance of the gas laser to scientific research. In 1993, he received the Albert Einstein World Award of Science of the World Cultural Council. On May 6, 2006, Javan was inducted into the National Inventors Hall of Fame.

THE HELIUM-NEON GAS LASER

Theodore Harold Maiman's ruby laser was the first working laser, demonstrated in May, 1960. It emitted pulsating bursts of light. His laser consisted of a synthetic ruby rod containing chromium atoms. Pulses from a photographer's flash lamp excited the atoms, creating pulsating bursts of red laser light.

The second working laser was Ali Javan's helium-neon laser, the first gas laser, demonstrated later that year. It converted electrical energy to a laser light and generated a continuous light beam instead of pulsating bursts of light. Javan's gas laser apparatus had an 80-centimeter-long quartz tube with an inner diameter of 1.5 centimeters. This tube contained a mixture of the inert gases helium and neon, and there were two internal electrodes used to send an electric current through the gas mixture. On both ends of the tube were reflecting and parallel mirrors.

Because inert gases do not easily combine with each other to form molecules, it was possible to isolate the atomic transfer of energy that is used at the first stage of the process, when the electrodes excited the atoms of helium gas with a current. The process began with the electric current stored as an internal energy in an energetic state of helium atoms, which then excited the neon atoms, whose atomic transitions produced the laser light. This light was then bounced between the mirrors and became rapidly amplified, increasing in intensity until a light beam was output from the apparatus. The mirrors could also be used to control the wavelength of the light. The power was low but very constant in this kind of laser, referred to as a continuous-wave laser. The output of Javan's gas laser was near infrared.

In 1962, researchers Alan D. White and J. Dane Rigden created a version of the laser that generated a visible red beam, the now standard 632.8-nanometer (nm) red line. In the mid-1970's, the gas laser was the first laser to be mass-produced, for use in Universal Product Code (UPC) scanners. It also became useful in holography, communications, information handling, construction alignment, surveying, medical technology, and laboratory demonstrations. Up until the late 1990's, the red helium-neon laser was the most common and profitable laser for low-power applications, since it was inexpensive to manufacture and provided a continuous, coherent low-power output at a visible wavelength.

IMPACT

With the invention of the helium-neon laser, Javan became an internationally acclaimed physicist and pioneer in laser technology. His gas laser was the first laser functioning on the principle of converting electrical energy to a laser light output. It was also the first to operate continuously—that is, to generate a continuous light beam. A significant scientific breakthrough, the gas laser became widely used in research and industrial laboratories, as well as practical applications such as Universal Product Code (UPC) scanners and holography.

It is significant that the day after its invention, the first experiment with a practical application for the gas laser involved a telephone call, because subsequent developments in fiber optics contributed to a revolution in communications, eventually forming the backbone of the Internet as well as telephony and media transmission. Javan's success with the gas laser helped to stimulate a wide range of future developments in laser research, including the use of other kinds of gases and materials such as semiconductor diodes to produce light.

Javan also directly contributed to the development of saturation spectroscopy, which made it possible to achieve unprecedented levels of precision in spectral analysis on the molecular and atomic levels. Ordinarily, lines of resolution at these levels are masked by thermal atomic motion, but the focused laser light can be used to eliminate the extra resonances caused by this motion.

—*Alice Myers*

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See also: Willard S. Boyle; Gordon Gould; Theodore Harold Maiman; Arthur L. Schawlow; Charles Hard Townes.

Al-Jazarī

Arab mechanical engineer

Al-Jazarī invented the first suction pump and developed segmental gears, floats, and conical valves, which were essential in the operation of water clocks and water-raising machines for irrigation.

Born: c. 1150; Al-Jazīra, Mesopotamia (now Diyarbakir, Turkey)
Died: c. 1220; probably Mesopotamia
Also known as: Badī ʿal-Zamān Abū al-ʿIzz Isma ʿīl ibn al Razzāz al-Jazarī (full name)
Primary field: Mechanical engineering
Primary inventions: Water-raising machines; water clocks; piston pump

Early Life

Mechanical engineer Badī ʿal-Zamān Abū al-ʿIzz Isma ʿīl ibn al Razzāz al-Jazarī, commonly known as al-Jazarī (ahl-JAH-zah-ree), lived in the city of Diyarbakir in what is now modern Turkey. From his name, it is known that he was born in al-Jazīra, an area between the Tigris and Euphrates rivers in what is now eastern Turkey. His name also reveals that he was unrivaled (Badī ʿal-Zamān). His date of birth, his childhood, and early education are unknown. It is likely that he was trained by his father, who also served as a court engineer.

Life's Work

From 1174 to 1206, al-Jazarī served as court engineer for three rulers of the Turkman Artuqid dynasty centered in Diyarbakir. Some of his ingenious machines, such as water clocks and fountains, served to entertain the young princes and to impress and amuse court visitors. Other devices, such as his phlebotomy measuring basins, had a practical application. Al-Jazarī lived during the flowering of Arab science, a time when advances occurred in optics, hydrology, astronomy, mathematics, and medicine. He was also fortunate to have lived under generous patrons during a period of peace and stability.

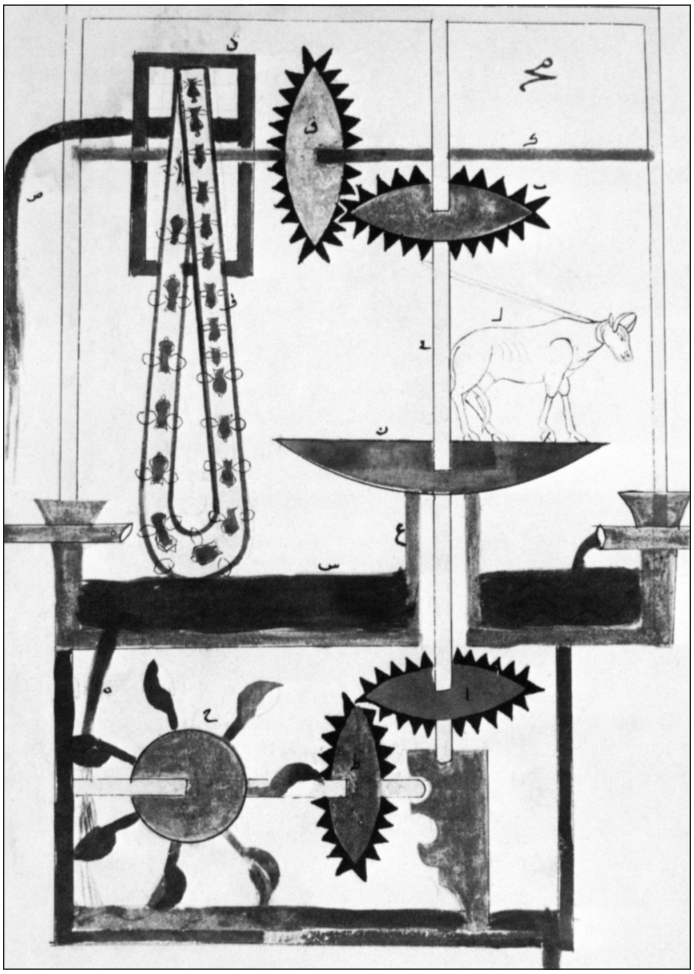
Unlike many engineers of his time, al-Jazarī was literate in written Arabic. He was also a skilled artisan and author. His accomplishments are known because King Nāsir al-Dīn asked him to write and illustrate a book about his machines. On January 16, 1206, al-Jazarī completed his book on theoretical and practical mechanics, *Kitāb fī ma ʿrifaṭ hiyal al-handasiyya*. It was not until 1974 that Donald R. Hill translated this book, *The Book of Knowledge of Ingenious Mechanical Devices*, from Arabic into English. The oldest and most complete copy of the book is at the Topkapi Sarayi Library in Istanbul and was copied by Muhammad ibn Yusuf ibn ʿUthman al-Haskafi on April 10, 1206. Fifteen manuscripts exist. Not all are complete, and some of the pages disappeared into private collections. Some of these copies are now at the Museum of Fine Arts in Boston and the Louvre in Paris. All illustrations are in color, and a school of miniaturists employed by the court illuminated the original manuscript. Other nearly complete copies are at the Bodleian Library at Oxford and the Hagia Sophia Library in Istanbul.

Al-Jazarī's book describes fifty devices, which he groups into six categories: (1) six water clocks and four candle clocks; (2) vessels and figures suited for drinking sessions; (3) ten pitchers and basins for phlebotomy and washing before prayers; (4) ten fountains and machines for the perpetual flute; (5) five water-raising devices; and (6) five miscellaneous devices that include combination locks, an alarm clock, a protractor, and a door for the palace. About 40 percent of the text is devoted to clocks. The instructions are clear and orderly. Each device is first presented with a general explanation of its operation and use. The details of manufacture and assembly are given and followed by a detailed discussion of the operation of the device. Accompanying the descriptions are 174 detailed and labeled drawings. The book summarizes most of the accumulated knowledge of mechanical engineering, and al-Jazarī provides a detailed guide for future artisans to recreate his machines.

Al-Jazarī's machines address practical problems of irrigation and commerce. He focused on water clocks to measure time for religious and commercial purposes. To what extent al-Jazarī had access to Greek scientific works translated under the patronage of the Abbasid dynasty is not known. He was familiar with the work of the ninth century Baghdad scholar Banū Mūsà, who wrote on *hiyal*, or trick vessels, such as fountains and musical automata. Al-Jazarī mentions reading Archimedes' treatise on the construction of water clocks. Much of al-Jazarī's discussion of calibration techniques, cranks, gears, control systems, and methods of casting metals by the use of mold boxes addresses improvements to existing technology. One device, a piston pump for raising water, is clearly a new invention by al-Jazarī.

Al-Jazari describes five water-raising machines. One improves upon the traditional animal-powered *sāqiya* by using water to drive the waterwheel that causes a chain of pots to raise the water. The device appears to be intended for ornamental purposes rather than for actual irrigation. Three other machines are modifications to the *shaduf*, or sweep. These modifications incorporate segmental gears and a machine-driven rather than the usual hand-driven crank. The fifth machine is an invention, a water-driven twin-cylinder pump that raises water to a height of about thirty-three feet, or ten meters. This machine addressed a particular irrigation problem for Upper Mesopotamia: how to raise water cheaply and efficiently from rivers whose beds lay below the surface of the surrounding fields. The important features of the device include the following: a double-acting principle, the conversion of rotary into reciprocating motion, and the use of true suction pipes. These features made possible the development of the steam engine and reciprocating pumps.

Water clocks existed in the ancient civilizations of Babylon and Egypt. Astrolabes and sundials measured only daylight hours, whereas water clocks worked at night. Water clocks measure time by a stopwatch-like function in which the length of a unit of time corresponds to the time that it takes for discharge of a liquid from one container to another. That movement of a liquid, usually water, through a series of tubes powered by gears, weights, and pulleys translates into signals that indicate the passage of time. Water clocks not only tell time but also serve an aesthetic or religious function by simulating the heavens and representing animals and humans that move and make sounds. Al-Jazarī's clocks and fountains feature figures that play musical instruments and falcons that spread their wings and disgorge metal balls from their beaks. These are entertainment robots, which also serve a function in the clock's operation. Some might say that the attention paid to decorative automata was a trivial exercise, but this criticism discounts the contribution made in the areas of delicate mechanisms and scientific instrumentation.



Al-Jazarī's water-powered sāqiya *chain pump.* (The Granger Collection, New York)

IMPACT

Al-Jazarī created no war machines. All of his machines either delighted the affluent or benefited society as a whole. Al-Jazarī's pumps were more advanced than the suction pumps used in Europe in the fifteenth century. Leonardo da Vinci mentions conical valves. It is not clear that da Vinci read al-Jazarī's book, although it is known that he read some of the translations of Arabic scientific works made in Toledo in the twelfth century. Al-Jazarī is mentioned by the Egyptian Al-Qalqashandī (1355 or 1356-1418) in his fourteen-volume encyclopedia as being preeminent in the science of machines.

Although al-Jazarī's book was copied and preserved in manuscript collections, it did not become a textbook, and no one in the Arabic-speaking world continued his work. The book remained untranslated until 1974. It is valuable as a history of the science and technology of that time. Reproductions of some of al-Jazarī's devices are on exhibit. A working replica of one of his water pumps is at the Institute for the

History of Arabic-Islamic Science at Johann Wolfgang Goethe University in Frankfurt, Germany. A replica of al-Jazarī's elephant clock is on exhibit in the Ibn Battuta Mall in Dubai. The World of Islam Festival in London in 1976 exhibited three reconstructions of his machines: a four-meter-high water clock, a phlebotomy device, and a double-acting pump. The English and Arabic translations and the exhibits of his working devices have stimulated a sense of pride and a desire by scholars to know more about the contributions of Arab scientists, engineers, and inventors.

—*Fran Hassencahl*

Piston Pumps and Water Clocks

Al-Jazarī is unique among his contemporaries because he wrote an illustrated book about his inventions. His major contributions were a piston pump for irrigation and improvements in water clock technology. His pump is driven by a paddle wheel, which drives, through a system of gears, an oscillating slot-rod. Two pistons attach to this rod and work in horizontally opposed cylinders, which connect to valve-operated suction and delivery pipes. As the slot-rod oscillates, one piston is on its delivery stroke and the other is on its suction stroke. The delivery pipes join above the center of the machine and form a single outlet into the irrigation system. The pump differs from conventional Hellenistic pumps that could not be positioned above the water source. Those pumps needed to be immersed in the water, which then could be collected on a suction stroke when the water entered through a hole covered by a plate valve in the bottom of the cylinder.

Al-Jazarī's elephant clock not only incorporates a highly decorated figure of an elephant but also has a receiving tank inside the elephant for the water that flows from a top tank. A sinking float in the bottom tank regulates the water flow. This closed-loop process with a float regulating water flow is analogous to the mechanisms of a flush toilet. The sinking of the float device triggers a ball-release mechanism that then tilts and empties the float. The empty float then rises to the surface of the water, and the process of delineating the rise and fall begins again and marks the passage of time. These valves and feedback mechanisms were essential to the development of the steam engine and automated controls.

Water clocks depend upon careful machining to achieve a constant rate of water discharge because time is measured by the amount of water as it moves through calibrated openings. Al-Jazarī's contributions in water clock technology include the use of carefully cast and fitted conical valves as in-line regulators in water flow systems and the development of float devices. He used emery powder to grind the seats and plugs of the valves to get a more watertight fit than did his predecessors. His casting of bronze and copper parts by using green sand in closed mold boxes did not occur in Europe until the end of the fifteenth century.

There is no evidence that al-Jazarī's mechanical devices transferred to Europe, but the principles of the suction pump and the refinement of conical valves were later incorporated into steam engine technology. His work is one of the efflorescences and declines that characterize the history of scientific discoveries and economic growth.

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See also: Archimedes; Leonardo da Vinci.

THOMAS JEFFERSON

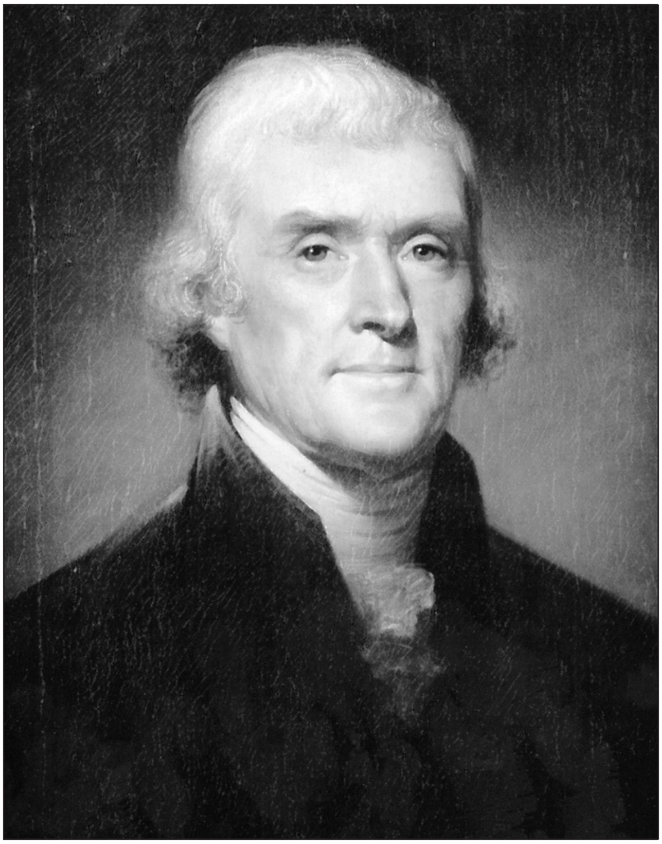
American architect, politician, and agriculturist

Besides serving as the third president of the United States, Jefferson was an architect, agriculturist, and inventor, designing such devices as an improved ox plow, the Great Clock at his self-designed Monticello home, and a lap desk—upon which he wrote the Declaration of Independence.

Born: April 13, 1743; Shadwell, Goochland County (now Albemarle County), Virginia
Died: July 4, 1826; Monticello, Albemarle County, Virginia
Primary fields: Agriculture; architecture
Primary inventions: Great Clock; portable copying press; improved ox plow

EARLY LIFE

Thomas Jefferson was the third of eight children born to Peter and Jane Randolph Jefferson. Peter was a surveyor and planter, and the Jeffersons homeschooled young Thomas until he was nine years old, when he began studying Latin, Greek, and French at a local school. Peter died when Thomas was fourteen and left him five thousand acres in Albemarle County on which he eventually built his famous home Monticello. He then attended a school near Gordonsville, Virginia, where he studied history and science. He also learned to play the violin around this time. Jefferson attended the College of William and Mary from 1760 to 1762, where he studied mathematics and philosophy, especially the British empiricists. He boarded in a building named for the British architect Christopher Wren and attended morning and evening prayers in a chapel also named for Wren. Biographers believe it was during this time that Jefferson purchased his first copy of sixteenth century architect Andrea Palladio's *I quattro libri dell' architettura* (1570), a classic architectural textbook that influenced Jefferson's own ideas on architecture. After graduation, he studied law and was admitted to the Virginia bar in 1767. In 1772, he married Martha Wayles Skelton, a widow, and they had six children. Unfortunately, only two daughters survived to adulthood, and Mrs. Jefferson herself died in 1782. He never remarried, although many biographers believe he had more children by his African American slave Sally Hemings.



Thomas Jefferson's official portrait. (White House Historical Society)

LIFE'S WORK

Based on a design he saw in James Gibbs's *A Book of Architecture* (1728), Jefferson began building his home Monticello in 1768. He started living in it in 1770, had it torn down and begun again in 1796, substantially completed the second version in 1809, and was still tinkering with it at the time of his death in 1826. Made of brick construction, the second version was influenced by houses Jefferson visited in France. The features of French architecture used at Monticello included a dome and the outward appearance that there was only one story, when in fact there are three. All the public rooms were on the first floor, so Jefferson did not see the need for a grand staircase. (Some visitors, however, complained about the narrow and steep stairways Jefferson designed.) The house also included two wine dumbwaiters to transport wine from the cellar.

"Monticello" means "little hill" in Italian, and building the house on a hill was itself an innovation at the time. Virginia plantation homes in the eighteenth century, such as George Washington's home, Mount Vernon, were normally built close to rivers. However, Jefferson took Palladio's advice that country houses should be built on high ground. In his 1968 book *Great Houses of the Western World*, Nigel Nicholson included Monticello as one of the thirty-six greatest homes in the world.

Jefferson had a second, lesser-known home called Poplar Forest. He inherited the land in 1773 from his father-in-law, John Wayles, and started building the house in 1806. It was the first house in the United States built in the shape of an octagon and included a central room that was twenty feet on each side and porticos on both the north and south sides.

Jefferson became a member of the Virginia House of Burgesses (the state legislature) in 1769 and the Continental Congress in 1775. He then became governor of Virginia in 1779 and served until 1781. He was a mediocre public speaker, especially when compared to his fellow Virginian Patrick Henry, so his main political activity was writing. The need for greater personal productivity inspired Jefferson to design a lap desk so that he could recline while writing. It contained what he considered to be the essentials for a writer, including a thermometer, quills, ink, paper, and a nightcap. He wrote the Declaration of Independence on an early model in 1776.

Jefferson sailed to Europe in 1784 as a diplomat and was the American ambassador to France from 1785 to 1789. During this time, he recruited architect Charles-Louis Clérisseau, author of *Antiquités de la France* (1788), a study of French buildings constructed during the Roman Empire, to provide drawings for the new Virginia state capitol building in Richmond. It was also during this time that he modified his lap desk to add a portable copying press, which could make two hundred copies in forty-five minutes. He invented the press when he found that his travels required a portable version of the copying press originally invented by James Watt. To use Watt's machine, the correspondent wrote with ink on a copper plate that could produce multiple copies. Jefferson's innovation was to reduce the machine's size so that it could fit on his lap desk.

Although Jefferson grew up in the countryside, it was on a trip from Paris to Amsterdam in 1788 that he observed an ox plow, which he could see was extremely inefficient. The problem, he felt, was in the moldboard, the part of the plow that actually makes contact with and tills the soil. Jefferson used mathematical principles to design a new one, which he finally built in 1794. He called it the "moldboard of least resistance." The first version had a square toe, but Jefferson quickly discovered that when the soil was moist, the toe accumulated dirt. He then built a second version with a sharp toe, which solved the prob-

THE GREAT CLOCK

Clocks fascinated Thomas Jefferson. One of the most striking features of Monticello, Jefferson's home, is the Great Clock, which was designed by Jefferson and constructed by Peter Spruck in 1792. Twenty-first century visitors to Monticello can still see it in operation in the entrance hall. Jefferson was a very organized person, and life at Monticello was as organized as he was. The clock had both an interior and exterior face so that everyone on the plantation was working on the same time. On the outside wall, the clock has only an hour hand, because Jefferson considered this sufficiently accurate for outdoor workers. A copper Chinese gong chimes each hour on the hour. During Jefferson's lifetime, it was loud enough for field hands to hear it anywhere on the plantation and reportedly could be heard as far as the University of Virginia in nearby Charlottesville.

On the inside, the clock displays not only the usual hour and minute hands but also a smaller dial to track the seconds. However, what was truly unusual was the day of the week indicator. Since it is a mechanical clock, it has to be powered by weights, of course. For his Great Clock, Jefferson utilized two sets of eighteen-pound cannon balls, which are suspended on both sides of the front doors. On Sundays, workers have to rewind the clock to raise the cannon balls to the ceiling. As the week goes by, the top ball on the right-hand set of weights shows the day and roughly even the hour as it gradually descends past markers on the wall. On Sunday, the cannon balls are toward the top and by Saturday have descended to the bottom.

There was one problem, however, during the installation process at Monticello. Jefferson originally designed the clock for the home he occupied while living in Philadelphia during his tenure as secretary of state. After Jefferson had the clock transported to Monticello in 1805, it was discovered that the height of Monticello's entrance was shorter than the length of the ropes connected to the cannon balls. Jefferson's solution was to cut square holes in the floor and allow the balls to be lowered until they entered the hole on Saturday and descended into the cellar.

lem. The early versions of the moldboard were made of wood, but Jefferson had an iron one built in 1814. In 1807, the French Society of Agriculture awarded him a gold medal for his achievement.

While serving as secretary of state from 1789 to 1793, one of his duties was supervising the U.S. Patent Office. Jefferson was elected vice president of the United States in 1796 and president in 1800, serving until 1809. One of his most important achievements as president was sending Meriwether Lewis and William Clark on a expedition from St. Louis to the Pacific Coast. He also established the first federal science agency, the Survey of the Coast, in 1807. As the named indicates, the agency surveyed and mapped the Eastern Seaboard. Jefferson's most important postpresidential achievement was the founding of the University of Virginia in Charlottesville in 1825. He died of natural causes in 1826.

IMPACT

Along with Benjamin Henry Latrobe (1764-1820) and Charles Bulfinch (1763-1844), Jefferson founded what became variously known as the Federal, Classical Revival, or neo-Palladian style of architecture in the United States. They believed that public buildings in the United States should be modeled on the buildings of ancient Greece or Rome, although Jefferson preferred the Roman style of architecture and Latrobe the Greek. While he was president, Jefferson appointed Latrobe to be surveyor of the public buildings of the United States.

Probably Jefferson's greatest impact was not for any one particular invention but for his role in determining the rules and regulations for obtaining a patent in the United States. Although he was only one member of the Board of Arts (the official name for the group that voted on patents) from 1790 to 1793, he dominated it by the force of his personality. He put emphasis on the utility, novelty, and nonobviousness of an invention in the decision of whether to grant a patent. For example, he rejected a 1791 patent application by Jacob Isaacks for a distillation process that converted saltwater to fresh water on the grounds that it was not a significant improvement on techniques already in use. On the other hand, he accepted the application by Eli Whitney for the cotton gin, because he recognized it as a genuine innovation.

Ironically, Jefferson never applied for a patent himself, because he did not agree with the concept of absolute intellectual property rights. He was not opposed to inventors receiving monetary compensation for their inventions, but felt that since patents are government-issued monopolies, they have the potential for abuse by stifling innovation rather than promoting it.

—*Thomas R. Feller*

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See also: Benjamin Banneker; David Bushnell; Oliver Evans; Joseph Priestley; Jethro Tull; James Watt.

ALEC JEFFREYS

British geneticist

Jeffreys developed DNA profiling (also known as DNA fingerprinting), a technique used to identify individuals by their unique genetic signature. The technique plays a critical role in forensic scientific analysis and has been used to link suspects to crime scenes, exonerate wrongly convicted individuals, and resolve paternity disputes.

Born: January 9, 1950; Oxford, Oxfordshire, England
Also known as: Sir Alec John Jeffreys
Primary fields: Biology; genetics; medicine and medical technology
Primary invention: DNA profiling

EARLY LIFE

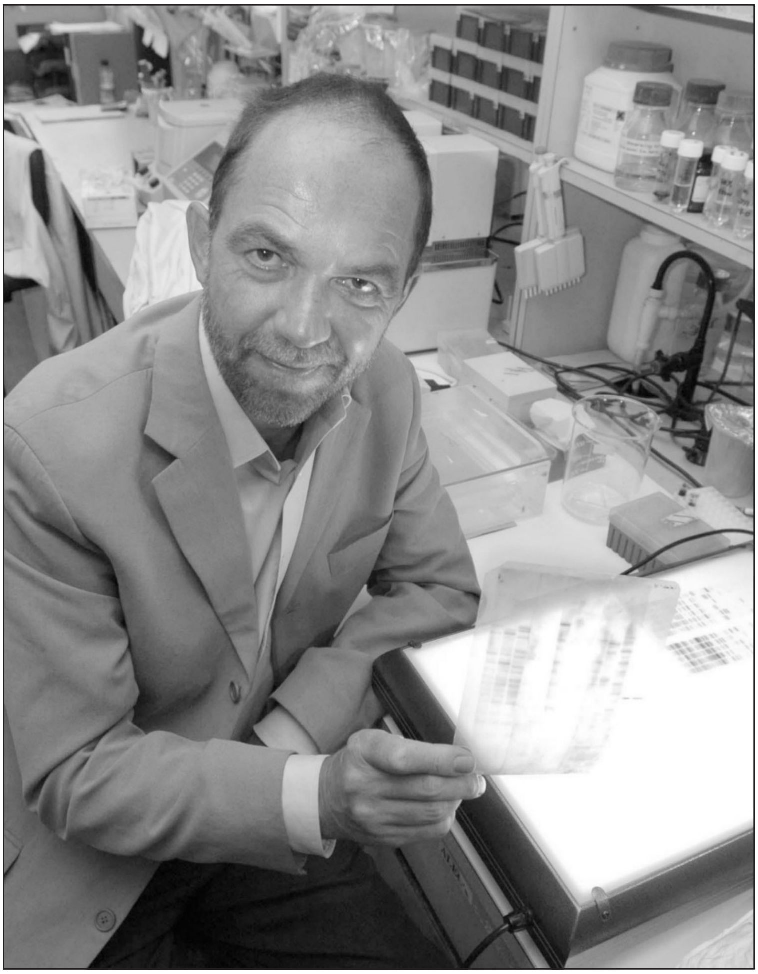
Alec Jeffreys was born into a middle-class British family in Oxford, England, and had one brother and one sister. Jeffreys came from an inventive family; both his father and grandfather had patents. His father encouraged his scientific inquisitiveness, giving Jeffreys a large chemistry set when he was eight years old. The young Jeffreys added to his collection of chemicals over the years, including a large bottle of concentrated sulfuric acid, a very dangerous chemical. His chemistry set was occasionally used to create minor explosions, and one incident left a permanent scar on Jeffreys' chin.

In addition to an early interest in chemistry, Jeffreys was drawn to biology. At about the age of nine, his father bought him a brass telescope. At twelve, Jeffreys made a dissecting kit that he initially used to dissect insects but that was later used to examine larger specimens, including, in one case, a dead cat he found on the road.

Jeffreys' formal education was less adventuresome but equally rewarding. He attended Luton Grammar School and Luton Sixth Form College before entering Merton College, Oxford. He graduated with a degree in biochemistry in 1972. He earned his Ph.D., also from Oxford, in 1975. That year, Jeffreys moved to the University of Amsterdam to work on mammalian genes as a research fellow. In 1977, he transferred to the University of Leicester, where he would develop the field of genetic fingerprinting, or deoxyribonucleic acid (DNA) profiling.

LIFE'S WORK

On the morning of Monday, September 10, 1984, Jeffreys was at his laboratory examining an X-ray of his lab technician's family's DNA when he realized that there were similarities and differences in the DNA sample. He quickly recognized the potential broad applications of this kind of DNA analysis, as it could be used to identify specific individuals as well as kinship. Jeffreys



Alec Jeffreys holds a copy of the first DNA profile at the University of Leicester, England. (AP/Wide World Photos)

DNA PROFILING

DNA profiling, or genetic fingerprinting, is a scientific process that forensic specialists can use to match the DNA of unknown persons to the DNA of readily identified persons based on a comparison of the similarities and differences in that small percentage of human DNA that differs between human beings.

Almost all human DNA, some 99.9 percent of it, is identical. However, until the morning of September 10, 1984, no one in the scientific community knew that patterns could be detected within the remaining tenth of a percent of human DNA. At 9:05 A.M. that day, British geneticist Alec Jeffreys noticed such patterns in his technician's family's DNA. This simple observation of similarities and differences in this small sample led to the equivalent of an earthquake in the scientific community, with profound consequences for all humankind. Initially, genetic fingerprinting was used to link the DNA of unknown persons to members of their family, or used to link certain unknown individuals to victims of crimes or to crime scenes. Soon it was applied to the remains of deceased persons to link them to certain known persons in order to make an identification.

Obtaining a reference sample from one person is a necessary first step. A sample of saliva, blood, semen, or other bodily fluid or tissue is taken from a living person. That person's unique DNA profile is then prepared and compared to other DNA profiles to see if there is a match. Jeffreys' initial technique used extraction of a restriction enzyme, followed by southern blot analysis. Thereafter, scientists developed a host of other and increasingly improved techniques—all of which flowed from Jeffreys' initial observation of the patterns in the tenth of a percent of human DNA that differs from person to person.

Once it became known that DNA patterns existed, the floodgates opened in nearly all aspects of genetic, as well as forensic, research. The Human Genome Project, which mapped the human genome, and medical research for a wide range of inherited disorders all benefited from Jeffreys' initial discovery. Archaeologists and animal researchers have also made use of DNA fingerprinting to identify remains and fill other gaps in their investigations.

initially called this new form of DNA analysis "genetic fingerprinting," since an individual's genetic profile is unique, like a fingerprint.

DNA profiling was first used to establish the identity of a British boy whose family came from Ghana. The immigration dispute was settled when the DNA results showed that the boy was related to the members of the family whose identity was not in doubt.

The genetic technique was first used in a police investigation to identify the rapist and murderer of two teenage females. The crimes were committed in Narborough, Leicestershire, in 1983 and 1986. British police had identified a suspect, Richard Buckland, whom they were confident would be convicted on circumstantial evidence. However, when his DNA sample was compared to that of the semen samples taken from the dead girls' bodies, the samples did not match. A subsequent investigation led to Colin Pitchfork, whose DNA was a perfect match to the semen samples. Jeffreys' technique had not only identified the rapist and murderer but also exonerated someone who faced the very real prospect of life in prison for a crime he did not commit.

In another case, German prosecutors wanted to be sure that the corpse of the notorious Nazi war criminal Dr. Josef Mengele was indeed him and not a decoy. Mengele was known as the "Angel of Death" at Auschwitz for sending thousands of Jews to their deaths. After the war, he evaded capture and fled to South America, where he died in 1979. In 1990, Jeffreys took DNA samples from the femur of the exhumed skeleton and compared it with the DNA of Mengele's widow and son, determining that the corpse was indeed that of Mengele.

Before genetic fingerprinting was commercialized in 1987, Jeffreys' laboratory was the only center in the world conducting DNA profiling. Since that time, the technique has been refined and used in multiple ways. Jeffreys was knighted in 1994 for his services to the field of genetics. His other honors include the Australia Prize (1998), the Louis-Jeantet Prize for Medicine (2004), and the Heineken Prize (2006).

IMPACT

Jeffreys' biochemical breakthrough had far-reaching ramifications. Rape and murder cases now routinely use genetic fingerprinting if traces of DNA can be found and connected to the victim or the crime scene. Numerous persons facing execution on death row have been exonerated because of DNA profiling, and criminals have been conclusively identified using this method. DNA fingerprinting has also been used to establish definitive proof of parenthood (paternity or maternity). The identification of long-dead individuals or charred bodies whose identity cannot be determined by conventional means are now resolved through DNA testing.

The field of DNA analysis has received major funding because it has proven to be an invaluable tool in forensic science. The Human Genome Project, begun in 1990, was made possible in part by Jeffreys' breakthrough.

—*Richard L. Wilson*

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See also: Herbert Wayne Boyer; Stanley Norman Cohen; Robert Charles Gallo; Mary-Claire King; Kary B. Mullis; Selman Abraham Waksman.

EDWARD JENNER

English surgeon and scientist

Jenner's discovery and development of smallpox vaccination began the eradication of one of the world's most dreaded diseases in the eighteenth century. He discovered the technique of inoculation with cowpox to prevent smallpox and coined the terms "vaccination" and "vaccine." Immunization saved lives around the world when Jenner's techniques were proven safe and became widely accepted.

Born: May 17, 1749; Berkeley, Gloucestershire, England
Died: January 26, 1823; Berkeley, Gloucestershire, England
Primary field: Medicine and medical technology
Primary invention: Smallpox vaccine

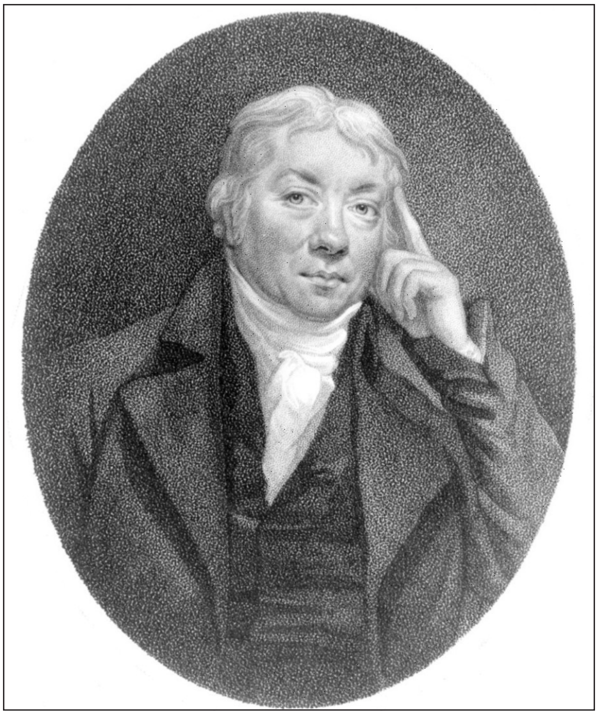
EARLY LIFE

Edward Jenner was born to Berkeley's local vicar, the Reverend Stephen Jenner, and his wife, Sarah, their eighth of nine children and their fourth son. Jenner's parents died in 1754, and he was raised by his elder brother Stephen and by an aunt, Deborah Hooper, who lived nearby on Clapton Farm. At the age of eight, Jenner enrolled in the Reverend Clissold's school in Wotton-under-Edge, then the Reverend Dr. Washbourn's school in Cirencester. As a youth, Jenner experienced variolation, whereby he was deliberately inoculated with material from smallpox sores, with the intention of generating a mild but protective case of smallpox. This was a fearful experience he remembered with horror.

At the age of thirteen, Jenner was apprenticed to Dr. Daniel Ludlow, a surgeon-apothecary in Chipping Sodbury, Gloucestershire. Jenner was always interested in nature, and his inquisitiveness and aptitude for the medical sciences was immediately recognized and encouraged. After another medical apprenticeship with George Hardwicke in Sodbury, and with his talents evidenced, he was granted private training in anatomy and surgery with noted surgeon John Hunter from 1770 to 1772 and at St. George's Hospital in London.

After his medical training was completed, Jenner served briefly as an army surgeon, then returned to set up his medical practice in Berkeley in 1772 in the west of England as a local physician. He continued his research and conducted local experiments, carefully recording his case studies and his clinical observations of his patients. Jenner received an offer from Hunter, his mentor, to form a medical partnership, but Jenner decided to remain in Berkeley and assist his community. Nonetheless, Jenner remained friends with and corresponded extensively with Hunter and other members of the Royal Society in London such as Joseph Banks (whose Pacific collection gathered on Captain James Cook's first voyage Jenner had helped catalog), Henry Cline, and Everard Home, both later presidents of the Royal College of Surgeons. Jenner was appreciated in London's highest medical and scientific circles and would be nominated for his Royal Society membership by Hunter.

Successful locally in the Berkeley countryside, Jenner bought his home, The Chantry, in 1785 and in 1788 married Catherine Kingscote. He had met her while conducting a balloon experiment in 1784, landing his hydrogen balloon in her father's park, Kingscote Park. The couple had three children, Edward (1789-1810), Catherine (1794-1833), and Robert Fitzharding (1797-1854). Jenner was awarded a medical degree from the University of St. Andrews in 1792. The early death of his son Edward at age twenty-one from tuberculosis and the frail health of his wife spurred Jenner toward making medical breakthroughs.



Edward Jenner. (Library of Congress)

LIFE'S WORK

A major cause of death in the eighteenth century was smallpox, and there had been a virulent outbreak in Gloucestershire in 1788. Jenner's Berkeley community was composed of rural farmers, and he noticed that many milkmaids who had worked with cows and come in contact with cowpox had clear complexions (smallpox survivors were disfigured by pock marks) and did not contract smallpox. He believed that cowpox might offer some form of immunity. A nursery rhyme would prove more than a myth as it affirmed: "'Where are you going, my pretty maid?' 'I'm going a-milking, sir,' she said. . . . 'What is your father, my pretty maid?' 'My father's a farmer,' she said. . . . 'What is your fortune, my pretty maid?' 'My face is my fortune,' she said."

Suspecting that working with cows had something to do with this immunity, Jenner tested his theory in May, 1796, when he vaccinated eight-year-old James Phipps with cowpox. Six weeks later, Jenner exposed Phipps to smallpox and found that the boy had become immune. Jenner's experiment revolutionized the world of medicine and launched the preventive phase of medicine (rather than relying merely on treatment). Jenner would be called the "father of immunology." He published results of his experimental vaccine in *An Inquiry into the Causes and Effects of the Variolae Vaccinae, a Disease Discovered in Some of the Western Counties of England, Particularly Gloucestershire, and Known by the Name of Cow Pox* in 1798. He wrote, "What renders the cowpox virus so extremely singular is that the person who has been thus affected is forever after secure from the infection of the smallpox; neither exposure to the variolous effluvia, nor the insertion of the matter into the skin, producing this distemper." He had replaced variolation with vaccination, using cowpox to prevent smallpox.

Variolation, whereby a patient was inoculated with a small amount of live smallpox virus, had been earlier introduced into English society by Lady Mary Wortley Montagu, who had seen it used in Turkey. Variolation had a mortality rate of about 0.5 percent, however, and variolated persons could infect others. Vaccination with cowpox was much less dangerous and could be inexpensively and widely used. In fact, Jenner opened his own home to dispense free vaccinations once a week. His first treatise was followed by his *Further Observations on the Variolae Vaccinae, or Cow Pox* (1799), *A Continuation of Facts and Observations Relative to the Variolae Vaccinae, or Cow Pox* (1800), and *The Origin of Vaccine Inoculation* (1801). Slowly, Jenner's ideas for inoculation against smallpox became widely accepted. By 1800, most English countrymen had accepted vaccination (in spite of some earlier skeptics who had drawn cartoons of people sprouting parts of cows from their bodies after being vaccinated with cowpox).

Vaccination against smallpox was Jenner's most successful accomplishment, but he enjoyed numerous others. Jenner had earlier formed a medical society in Rodborough that met at the Fleece Inn and another at the Ship Inn in Alveston before which he had read medical treaties on ophthalmia, angina pectoris, and valvular heart disease and presented his cowpox experiments. He was elected to membership in the Royal Society in 1789 based on his findings of the nesting behavior of the cuckoo bird. He discovered through observation (and was later proven right by photography) that the cuckoo bird's mother deposits her eggs in a bird's nest of another species (such as a hedge sparrow) and that the hatched cuckoo nestlings hoist the host eggs or nestlings out the nest by lifting them into the hollow of the cuckoos' backs and pushing them up and out of the nest. The foster parents continue to feed the cuckoo nestlings as their own. Jenner's correct observation of this eviction behavior was published in the *Philosophical Transactions of the Royal Society* in 1788. He was made an honorary member of the Geological Society in 1809, and ten years later he discovered a fossil specimen of a plesiosaurus, the first to be identified in England. In 1823, he read his paper "Some Observations on the Migration of Birds" before the Royal Society that helped to prove that birds did indeed migrate and not merely hibernate during the winter.

Jenner was a true man of the Enlightenment who worked with a number of key scientific ideas. He remained devoted to his work as a doctor all his life and made his house visits by horseback, servicing an area of more than four hundred miles. Most often he received his patients at The Chantry (now the Edward Jenner Museum). He dressed in a blue coat with yellow buttons, wore polished boots, and wore his hair in a club. He remained a member of the landed gentry and established a large clientele among the aristocracy and local gentry, remaining lifelong friends with his in-laws and Lord Berkeley. Jenner established a second home in Cheltenham, near London, and was the founder and president of the Cheltenham Literary and Philosophical Institution, all the while promoting his personal cause of vaccination of the general population. Jenner died of a stroke suffered at his home in Berkeley on January 26, 1823.

SMALLPOX VACCINE

On May 14, 1796, British physician Edward Jenner performed a vital experiment by making two half-inch scratches on the arm of eight-year-old James Phipps and dabbing cowpox pus into them. The pus had come from the cowpox blisters on the hands of milkmaid Sarah Nelmes, who had milked a cow infected with cowpox, as evidenced by lesions on the teats and udder. Phipps developed symptoms of mild cowpox but suffered no long-term effects. Six weeks later, Jenner exposed Phipps to smallpox virus in the same manner that he had exposed the boy to cowpox, but Phipps did not become ill. When Jenner exposed Phipps to cowpox, the boy's immune system developed antibodies ready to combat the virus, and these same antibodies were capable of fighting off the similar smallpox virus. Jenner realized that his experiment had worked, and the persons he treated with cowpox developed resistance to both cowpox and smallpox.

Vaccination with cowpox fluids helped to contain smallpox, a highly destructive disease that can kill up to one-third of its victims and that permanently scars many survivors. Jenner called his idea "vaccination," from the Latin word *vaccinia*, meaning "cowpox," and coined the word "vaccine," from the Latin *vacca*, meaning "cow." He also introduced the word "virus." The last case of smallpox occurred in 1977, and the World Health Organization (WHO) declared the disease eradicated in December, 1979.

IMPACT

Vaccination as a means of producing immunity against pathogens was pioneered by Jenner and clearly saved lives. Death from smallpox fell drastically across Europe. Immunology was developed as a science. The British parliament considered Jenner a medical hero, awarding him £30,000 to pursue additional vaccination experiments and the development of preventive treatments. Louis Pasteur adopted the word "vaccination" for immunization against any disease. The British army and navy were vaccinated as early as 1801, and Jenner was awarded a gold medal by British naval officers in recognition. Foreign dignitaries inquired about immunization. By 1803, Jenner had established the Royal Jennerian Institute, which encouraged vaccination to eradicate smallpox, and by 1808 this had grown into the National Vaccine Establishment. In 1805, Jenner became a member of the Medical and Chirurgical Society, further encouraging immunization, and this organization expanded into the Royal Society of Medicine, capitalizing on his prestige and influence in the realm of medical science.

Jenner's vaccination techniques and renown spread worldwide. The empress of Russia even changed the name of the first Russian child vaccinated to "Vaccinoff" to celebrate the accomplishment. So great was Jenner's influence that Napoleon I, in 1805, still at war with England, released British prisoners at Jenner's personal request. Vaccination was first utilized in the United States by Benjamin Waterhouse, Harvard University's first professor of pharmacy. In 1821, Jenner was promoted to physician extraordinary (honorary title) to King George IV. Jenner accepted a fellowship at the Royal College of Physicians of Edinburgh and received honorary doctorates from Oxford and Harvard universities. He was honored by his local community by being named mayor of Berkeley and justice of the peace in recognition of his famed contributions to world health.

—*Barbara Bennett Peterson*

FURTHER READING

Baron, John. *Life of Edward Jenner*. 2 vols. London: H. Colburn, 1827-1838. Dr. John Baron was an enthusiastic supporter of Jenner and his official biographer. He describes Jenner's genius as a well-trained researcher and original thinker who contributed greatly to the eradication of smallpox. Lists Jenner's numerous awards and diplomas.

Baxby, Derrick. *Jenner's Smallpox Vaccine: The Riddle of Vaccinia Virus and Its Origin*. London: Heinemann Educational Books, 1981. Contributes to the discussion of types of cowpox identified by Jenner—"true" cowpox and "spurious" cowpox—and why in certain cases the virus strains might produce varied results.

Bazin, Hervé. *Eradication of Smallpox: Edward Jenner and the First and Only Eradication of a Human Infectious Disease*. Translated by Andrew and Glenise Morgan. San Diego, Calif.: Academic Press, 2000. An interesting and well-researched biography originally written in French that explains the impact of Jenner's scholarly research and his development of smallpox vaccination throughout the world.

Redmond, Shirley-Raye. *Edward Jenner*. San Diego, Calif.: Blackbirch Press, 2006. An excellent biography utilizing sources from around the world to produce an up-to-date appraisal of the father of immunology and illustrating his creative research techniques.

See also: Robert Charles Gallo; Louis Pasteur; Jonas Salk.

THOMAS L. JENNINGS

American businessman

Jennings innovated a dry-cleaning technique to wash stains from garments without using water immersion and agitation. He submitted an application registering that procedure with the U.S. Patent Office, obtaining the earliest-known patent issued to an African American.

Born: 1791; New York, New York
Died: February 11, 1859; New York, New York
Primary field: Chemistry
Primary invention: Dry cleaning

EARLY LIFE

Thomas L. Jennings was born during the last decade of the eighteenth century in New York City. Most sources state his birth year as 1791, based on two obituaries written soon after his death in winter, 1859, which say that Jennings was sixty-eight years old. According to the 1850 U.S. Census, Jennings was fifty years old as of August 1, 1850, and he was fifty-five when the New York State census was taken in 1855, suggesting he was born around 1799. Neither record indicates who provided Jennings's age to census enumerators and how they knew that information.

Sources describe Jennings as a free African American without clarifying if he or his parents were ever enslaved and, if so, how Jennings secured his freedom. They do not tell who Jennings's parents were, nor do they specify what name his middle initial represents. In 1790, near the time of Jennings's birth, 1,011 free blacks and 2,369 slaves lived in New York City, composing 9.7 percent of that city's population. Jennings was free in 1820 when he applied for a patent.

Few details about Jennings's childhood are known, except that as a boy he began working as an apprentice to a New York tailor who, sources vaguely commented, was an acclaimed man. Jennings acquired skills to create and modify clothing to meet customers' specifications. No facts confirm that Jennings attended school, but his activities as an adult reveal that he was knowledgeable and literate, writing documents discussing legal issues. During the War of 1812, he dug trenches on Long Island to protect the city.

Jennings married a woman named Elizabeth, who had been born in New Jersey and was five years younger than him. They lived at 167 Church Street in the Fifth Ward of New York County and had two daughters, Elizabeth and Matilda, and two sons, Thomas and William. In addition to earning income from making clothes, Jennings operated a boardinghouse.

LIFE'S WORK

Jennings concentrated on a tailoring career after being employed in several other positions. He offered his services to customers who sought alterations for their clothing or desired new garments, which he designed and fitted. The quality of his craftsmanship attracted more clients, both in the city and elsewhere, who traveled to hire Jennings to assist them with their clothes, as people recommended him and promoted his work. Profiting from his sewing talents and entrepreneurial abilities, Jennings invested his income to establish a clothing store located on Church Street that developed into a prominent garment business.

In the late 1810's, Jennings contemplated how to resolve a common complaint his customers voiced regarding their clothing becoming stained. Instead of keeping their dirty clothes, some people replaced them if they could afford to do so, although many customers did not have that option. Jennings sought ways to clean and restore garments, stressing that he wanted to assist less prosperous clients and to prevent people from discarding clothes he had invested his time and skills to make. He realized that regular washing techniques using water might damage fragile materials.

Jennings evaluated the effectiveness of applying chemicals used by tradesmen for cleaning tasks in other professions to remove stains from diverse fabric samples. He mixed chemicals together in varying ratios until he probably determined that turpentine was the most useful cleaning fluid to lift greases and oils from fabrics without harming materials. No available information reveals whether he constructed machinery for his process. Jennings offered his innovative cleaning procedure, referring to it as dry scouring, to his clientele.

DRY SCOURING

Thomas L. Jennings developed a practical dry-cleaning technique in response to his customers' demands. Because a fire burned Jennings's patent record, his description of dry scouring and specific information regarding his invention are unavailable. Historians hypothesize Jennings recognized that turpentine, a fluid many craftsmen used for cleaning tasks to remove greases and oils, could be used to launder fabric. Jennings probably evaluated different quantities of turpentine to determine the minimum amounts that would be effective when used on diverse materials. He possibly also combined turpentine with other chemicals to strengthen his cleanser. Jennings's dry-scouring technique might have relied on turpentine evaporating and lifting dirt from fibers.

Histories of dry cleaning do not mention Jennings's patent or acknowledge whether it inspired any other inventors in the United States or elsewhere. Instead, accounts comment that some nineteenth century Europeans used lamp fuels composed of turpentine spirits to clean cloth. After turpentine brushed on stained material dried, grime disappeared. In 1855, a Parisian, Jean Baptiste Jolly—often credited as the founder of commercialized dry cleaning—established a laundry based on using turpentine and chemicals to clean fabrics. Nineteenth century chemists created such solvents as benzene, which dissolved oils and fats that water could not disintegrate. Fibers did not swell when exposed to these solvents, preventing garments from shrinking as they did when laundered in water. Solvents did not damage most materials or alter their colors. Dry cleaners realized that they could expose entire garments, curtains, and other fabric items to solvents instead of just dabbing areas.

Knowledge of dry-cleaning technology and methods extended internationally, and more businesses offered dry-cleaning services to generate income from a process that was not as time-intensive as traditional laundry methods, which appealed to customers. By the early twentieth century, many dry cleaners used petroleum-based solvents, which increased risks of fires and explosions. Professional organizations, including the National Association of Dyers and Cleaners, established standards such as using dry solvents, which were replaced with synthetic solvents developed in the 1970's. Perchloroethylene, a frequently used synthetic solvent, was safer and nonflammable. In the late twentieth century, scientists continued to develop dry-cleaning solvents to be more environmentally sound, such as those patented by GreenEarth Cleaning. The U.S. Patent Office approved patents for dry-cleaning devices, solvents, and techniques from the 1880's through the early twenty-first century, but none, even New York City resident James Baker's 1912 dry-cleaning machine patent (number 1,028,317), reference Jennings's invention.

This early form of dry cleaning pleased Jennings's customers and secured him more business producing clothes and cleaning them.

Aware that customers spread news of his successful dry scouring work, Jennings sought to protect his invention from other people appropriating his techniques without reimbursing him. In 1820, he submitted a patent application to the U.S. Patent Office. Sources do not indicate whether Jennings initiated the patenting process alone or whether he had legal counsel who assisted him, nor do they identify witnesses who signed his application. At the time Jennings applied, patents did not state the race of individuals patenting inventions, and the Patent Office did not discriminate against inventors based on ethnicity. The 1793 patent law in effect at that time permitted both free and enslaved African Americans to secure patents.

Jennings received a U.S. utility patent on March 3, 1821, for his invention entitled "Dry Scouring Clothes." He framed the certificate, which bore the signatures of Secretary of State John Quincy Adams and Attorney General William Wirt. The Patent Office listed Jennings's invention in a contemporary publication noting registered patents. Although most historians credit Jennings as the first African American to receive a patent, there could have been prior African Americans who achieved patents who have not yet been identified. Jennings's patent became well known because Frederick Douglass mentioned it in a eulogy praising Jennings in the April, 1859, issue of *The Anglo-African Magazine*.

The Patent Act of 1836 resulted in patents receiving numbers listed chronologically from the time they had been first issued, assigning patent number 3,306x to Jennings's invention, with the *x* indicating that the patent had been registered before 1836. A December 15, 1836, fire at the U.S. Patent Office burned most patent records stored there, including Jennings's application and any associated materials supporting it. Without that application, specific information and Jennings's description of his invention remain uncertain. His dry scouring invention was the sole U.S. patent he obtained. Sources do not mention if he sought foreign patents or ever attempted inventing any other processes or objects useful to his business.

Jennings generated ample income from his patent, although records do not specify any monetary amounts. Some sources claim that Jennings initially used profits to purchase enslaved relatives, suggesting that perhaps his parents or his wife's family were slaves. In 1820, 10,368 free African Americans and 518 slaves resided in the New York City area. Jennings invested his patent earnings into bettering his community, particularly funding abolition efforts. He promoted suffrage for African Americans and educational opportunities and participated in civic groups devoted to political, economic, and intellectual activities. Jennings helped the Phoenix Literary Society provide clothes to impoverished children so they could attend schools.

After New York ended slavery in 1827, Jennings voiced his opinions regarding issues that many free African Americans experienced, especially prejudices and animosity. *Freedom's Journal*, the first African American newspaper in the United States, printed one of his speeches in its April 4, 1828, issue. He was a delegate to People of Color conventions in the 1830's. In 1837, Jennings took petitions demanding African American suffrage to the state legislature. He organized the Legal Rights Association in 1854, serving as president, to seek equal transportation services for blacks after his daughter experienced discrimination on a public omnibus. When Jennings died at his home on February 11, 1859, his framed patent was displayed by his bed.

IMPACT

Jennings's inventiveness achieved professional and personal results. In addition to providing a useful cleaning service to his community, Jennings gained financial means to enhance his business and lifestyle and reinforce his efforts to seek legal changes to improve conditions for African Americans. Whether Jennings was aware the process of inventing and patenting would assist him economically and socially is unknown. Sources do not reveal whether Jennings had any access to other inventors who might have motivated him to pursue innovative efforts and suggested potential benefits, both immediate and future.

Although Jennings's contemporaries were aware of his invention, or at least of the novel dry scouring he offered, no records indicate how Jennings might have inspired other African American inventors or convinced skeptics of African Americans' technological and scientific abilities. Other dry cleaners might have appropriated aspects of Jennings's invention for variations they developed but for which they did not seek patents, which might have confirmed his influence.

Many antebellum African American craftsmen and laborers devised objects or methods to resolve problems they encountered. Often, those inventors did not seek patents, or other people, particularly slave owners, claimed patents for those inventions. The U.S. Patent Office first identified an African American inventor thirteen years after Jennings's received his patent when the race of Henry Blair, a free African American, was included on his 1834 and 1836 patents for agricultural tools. No records connect Blair and Jennings or suggest that Jennings inspired Blair to file for patents. Many sources incorrectly identify Blair as the first African American patent holder.

African American congressman George Washington Murray did not include Jennings in his list of African American inventors for the *Congressional Record* in 1894, nor did Henry E. Baker, an African American patent examiner, who published information he compiled regarding African American inventors. Those omissions could have occurred because Jennings's patent was overlooked because of destroyed records, because his race was unknown to those men, or because his invention achievements were no longer publicized after his family, customers, and peers died.

—*Elizabeth D. Schafer*

Further Reading

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Freeman, Rhoda Golden. *The Free Negro in New York City in the Era Before the Civil War*. New York: Garland, 1994. Historical depiction of Jennings's community, noting Jennings's civic work and providing statistics, contemporary perceptions regarding free African Americans, and diverse ways slaves obtained freedom. Illustrations include an 1855 city map.

Harris, Leslie M. *In the Shadow of Slavery: African Americans in New York City, 1626-1863*. Chicago: University of Chicago Press, 2003. Discusses groups and activities in which Jennings participated, especially conventions and relief organizations, to promote abolition and suffrage efforts for African Americans. Citations identify useful primary sources.

Hewitt, John H. "The Search for Elizabeth Jennings, Heroine of a Sunday Afternoon in New York City." *New York History* (October, 1990): 386-415. Presents biographical details about Thomas Jennings, identifying him as a tailor and merchant, not inventor, and depicts how his contemporaries reacted to his daughter's trial and his efforts to integrate transportation.

Sluby, Patricia Carter. *The Inventive Spirit of African Americans: Patented Ingenuity*. Westport, Conn.: Praeger, 2004. Comprehensive history written by a patent agent and expert emphasizes Jennings's significance as a pioneering patent holder. Appendixes, bibliography, and illustrations, many from the author's collection.

See also: Elias Howe; Charles Macintosh; Roy J. Plunkett; Levi Strauss.

STEVE JOBS

American computer engineer

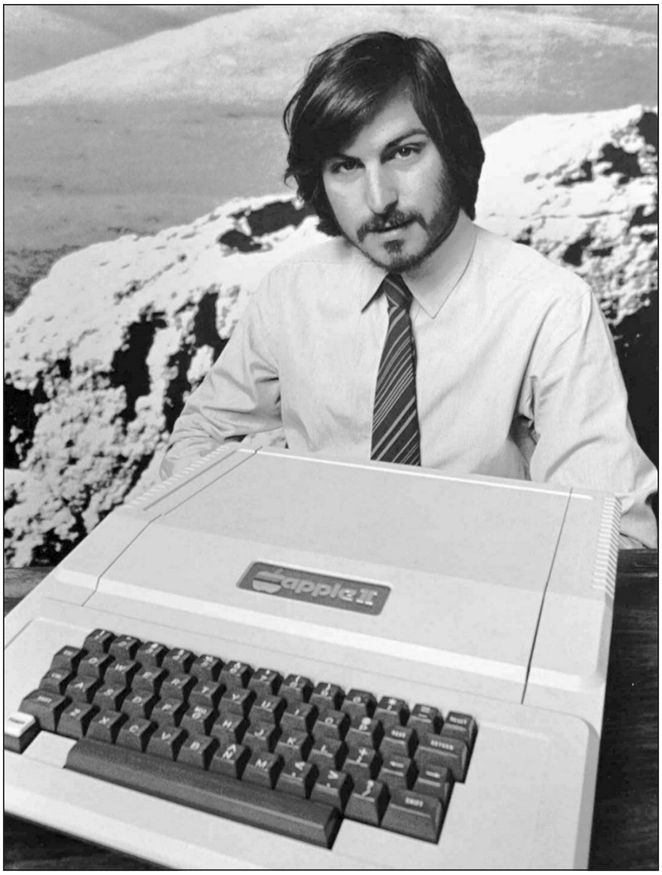
Jobs developed a career based on continuous innovation in the computer and consumer electronics industry, focusing on devices that are simultaneously elegant in design and inviting for ordinary people to use.

Born: February 24, 1955; San Francisco, California
Also known as: Steven Paul Jobs (full name)
Primary field: Computer science
Primary inventions: Apple computer; iPod

Early Life

Steven Paul Jobs was born in San Francisco on February 24, 1955, to a young unwed mother. At that time, an out-of-wedlock birth was considered a disgrace and would have limited the prospects of both mother and child, so she gave him up for adoption. A few weeks later, he entered the home of Paul and Clara Jobs. Young Steve showed his strong-willed side at an early age. He also demonstrated considerable energy and curiosity, traits that constantly got him into trouble. However, his intellectual activities were not confined to exploring the physical world. He had learned to read before he entered school and was frequently bored there. He resisted busywork, and he often focused his formidable intellect on exploiting the weaknesses of any teacher who displeased him. In third grade, he systematically misbehaved until he was expelled from school.

The following year, his teacher realized that she had a



Steve Jobs with the Apple II computer. (AP/Wide World Photos)

bright but unmotivated student on her hands and set out to harness his untapped talent. She quickly discovered that he could be bribed with money to actually turn in good schoolwork. Once she got a measure of his actual talents, she recommended that he be allowed to skip fifth grade and enroll midterm in sixth grade. The school had serious problems with rough students, however, and Steve was so disgusted that he informed his parents he would not be returning for seventh grade.

Rather than force a confrontation, Paul and Clara Jobs relocated to a better district. Steve became increasingly interested in electronics, and an encounter with Bill Hewlett led to a summer job at Hewlett-Packard. Steve also met Steve Wozniak, who was sufficiently impressed with his knowledge of electronics to overlook the difference in their ages.

While a student at Reed College, Jobs became interested in Eastern religions, and in 1974 he took a trip to India. There he dressed in a pilgrim's loincloth and made his way around the country by begging and doing odd jobs while he visited various shrines and learned at the feet of holy men. During his trip, he contracted dysentery and quickly learned the importance of creating a world in which people's physical needs were met so that they could be free to explore their spiritual needs.

LIFE'S WORK

Upon returning to the United States, Jobs went back to work for the popular video game manufacturer Atari, which had hired him in 1974. There he became involved in a project to create a new game called *Breakout* and got his old friend Wozniak to do the actual programming. However, Jobs also concealed just how much Atari was paying him, which would later create bitter feelings between the two men. Wozniak introduced Jobs to the Homebrew Computer Club, a group of computer hobbyists. As Jobs helped his friend create what was called the "Cream Soda Computer," he realized how useful a computer could be if it had an easy-to-use interface. He decided that it should also have an inviting appearance and a name that created friendly associations.

On April 1, 1976, Apple Computer was born. Although the original five hundred Apple I computers were kits aimed primarily at the hobbyist market, the Apple II was a complete machine that came in a warm tan case made of plastic with rounded edges and corners. The Apple II was also innovative in using floppy disks rather than magnetic tape to load programs and data into working memory, speeding up access to stored information. This design required more expensive parts than Wozniak and Jobs had capital to purchase. As a result, Jobs had to woo venture capitalists, a process made difficult by his own lack of business experience. However, investor Mike Markkula was open-minded enough to see the potential of these two young men's plans and was willing to work out such fundamentals as a business plan and a formal budget. Satisfied that they could take his advice, Markkula secured them funding and moved them out of their garage workshop into a building in Cupertino, California. On January 3, 1977, formal incorporation papers were signed and Apple Computer, Inc., became a legal entity.

Jobs refused to be satisfied with the success of the Apple II, which still required the user to type commands into a command-line interface. He had become convinced that the personal computer could succeed only if it became an appliance, its inner workings effectively invisible to the end user. During a visit to the Xerox Palo Alto Research Center (PARC), Jobs saw an experimental graphical user interface (GUI). The point-and-click simplicity so impressed him that he decided to base Apple's next generation of computers on them, and thus was born the Macintosh, or Mac, released shortly after the 1984 Super Bowl game.

By 1985, trouble had come to Apple, and Jobs was ousted from his own company by John Sculley, the very man he had brought from PepsiCo to help Apple get through the "adolescent transition" between small business and major corporation. Set adrift, Jobs started another computer company, NeXT, to design a high-powered graphics workstation. However, the market was not yet ripe for that particular niche, and NeXT struggled for several years before getting out of the hardware business entirely and concentrating on the NEXTSTEP operating system (OS). Jobs had more success as the head of Pixar, a company dedicated to graphics processing for the motion-picture industry. Although the earliest versions of *Toy Story* (1995) were rejected by Disney, a revised version proved a box-office runaway.

In 1997, Apple was in bad shape, and there was a serious possibility that it would close its doors altogether. The Macintosh operating system that had been so innovative in 1984 had not received a serious makeover in years, and competition from Microsoft Windows was intense. After trying several stopgap measures, Apple executives finally approached Jobs in order to gain access to the NEXTSTEP OS as the basis of a new version of the Mac OS. After several months of delicate negotiations, Jobs returned to Apple and simplified the company's confused product line. In 1998, he introduced the iMac, a compact computer with innovative universal serial bus (USB) connectors.

By the year 2000, Apple was back on its feet again, and the 2001 introduction of the iPod music player secured its future as a growing company. Throughout the first decade of the twenty-first century, the iPod went through multiple versions, eventually spawning the iPhone, a combination cellular phone, personal digital assistant (PDA), and music player with a slick, sophisticated interface.

IMPACT

Jobs has been a force for ongoing innovation in the computer and personal electronics industry, consistently anticipating consumers' needs and seeking to create products that would fill those needs even before people knew they had them. However, his insistence on technical elegance has often meant that his products have borne a premium price tag that not all users have been willing to pay, leaving his companies vulnerable to being undercut by

THE IPOD

Although digital audio players (usually called MP3 players) had existed before the iPod, they generally had little memory, confusing controls, limited features, and a clunky appearance. MP3 players were not regarded as a serious substitute for a portable cassette or CD player. When Steve Jobs introduced the iPod in 2001, he gave the world an MP3 player that was both elegant and functional. The smooth white plastic surface of its case had a sensuous quality that fairly begged to be handled, and it looked handsome enough that a user would want to wear it on a sleeve or a belt rather than hide the device. (However, as the iPod craze took off, many people found it prudent to keep their iPods out of sight when on the street, lest they have the much-sought-after devices stolen right off their bodies.) In 2007, the iPod became the best-selling digital audio player in history, having sold more than 110 million units worldwide.

In addition, the iPod used a laptop hard drive rather than flash memory as most early MP3 players used. This feature enabled the iPod to provide much more capacity, although at the cost of some battery life and ruggedness. However, carefully designed software allowed songs to be loaded from the hard drive into a buffer. This feature simultaneously reduced battery drain and decreased the chance that a sudden shock could crash the hard drive.

The interface by which the user controlled the iPod was also given careful thought. The menu system was based to some degree on that of the Apple Macintosh operating system. The touch wheel and its successor, the click wheel, enabled the user to move smoothly from one menu to the other, controlling multiple playlists with ease. However, after several versions of the iPod had come out, Apple discovered that many users seldom used the playlist system. Instead they preferred to use the shuffle function to have their iPod play songs at random from their entire music library. As a result, Apple introduced the iPod Shuffle, a thumb-sized device with no screen and with a simplified click-wheel control that was always on shuffle play.

Although many iPod owners stocked their iPods with songs from their existing CD collections, Apple also provided users the option of buying single songs and entire albums in the form of digital downloads from the Apple iTunes online music store.

competitors willing to produce a product of lesser quality that is merely good enough rather than the very best. Nevertheless, Jobs reinvigorated Apple after he returned to the company in 1997 and introduced a simplified product line that included the iMac.

—Leigh Husband Kimmel

FURTHER READING

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See also: Nolan K. Bushnell; Tony Fadell; Bill Gates; Ted Hoff; Dean Kamen; Steve Wozniak.

ELDRIDGE R. JOHNSON

American businessman

Johnson was the technological and industrial forefather of the modern recording industry.

Born: February 18, 1867; Wilmington, Delaware
Died: November 14, 1945; Moorestown, New Jersey
Also known as: Eldridge Reeves Johnson (full name)
Primary fields: Manufacturing; music
Primary inventions: Victrola phonographs; spring-driven motor for phonographs

EARLY LIFE

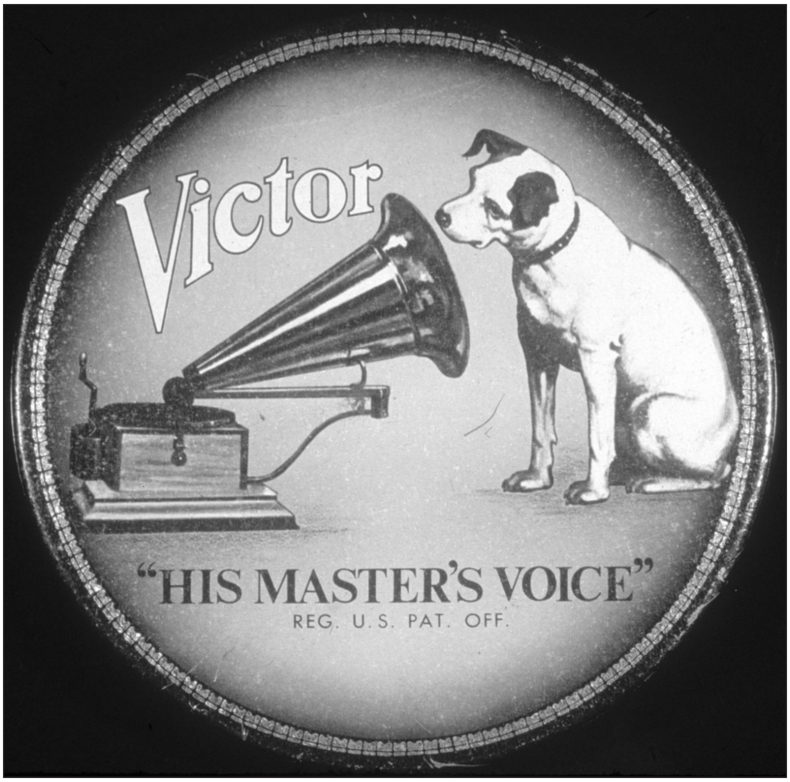
Born in Wilmington, Delaware, in 1867, Eldridge Reeves Johnson was the son of Asa S. Johnson, a home builder, and Caroline Reeves Johnson. When Eldridge was two years old, Caroline died. He was raised by his great-aunt Elizabeth and uncle Dan on a farm in Bethel Church until age eleven, when he returned to live with his father. Johnson then attended Wesley Conference Academy (now Wesley College), graduating in 1882, at age sixteen. A teacher at the academy strongly discouraged him from continuing in higher education because of his poor scholastic record. He found work as an apprentice with Jacob Lodge and Son, which manufactured press equipment. From 1882 to 1886, in Philadelphia, Johnson attended night classes at the Spring Garden Institute that were actually machine shops operating in an eight-hour workday. The apprenticeship proved to be arduous, difficult work and reinforced his desire to start his own business.

Johnson finished his apprenticeship and found employment at the Standard Machine Shop in Camden, New Jersey, in 1886. His partner, John Scull, died suddenly in 1888. Johnson constructed an automatic bookbinder from Scull's records and experiments, his first invention. He formed the New Jersey Wire Stitching Machine Company to promote sales of the bookbinder, which was initially unsuccessful until years later when the demand for stitchers increased.

With eight years of salary savings, Johnson purchased the business from John Scull's father, Captain Andrew Scull, who was the original owner, and renamed it the Eldridge R. Johnson Manufacturing Co. Bookbinding was already a well-established industry, so Johnson's overwhelming curiosity and interest in the talking machine took center stage.

LIFE'S WORK

Emile Berliner had invented the disc phonograph as an alternative to Thomas Alva Edison's cylinder phonograph. To play a recording on a gramophone, it was necessary to constantly hand-crank the machine, attempting to maintain 150 revolutions per minute. This proved to be a nearly impossible task, and it caused the needle to skip. In 1895, Berliner approached Johnson about manufacturing a device that could engage the gramophone turntable at a steady speed. Although Johnson was intrigued by the potential of this new music machine, he regarded it as poorly designed, with a scratchy, ill-defined sound. Johnson developed a spring-driven motor that produced a consistent turntable speed. As a result, his company became the gramophone's primary manufacturer. The spring motor proved to be the improvement needed to make the machine more commercially viable.



A Victor record label from 1900 with the dog Nipper and the famous slogan. (Getty Images)

In 1900, Johnson owned the Consolidated Talking Machine Company. He purchased a painting titled *His Master's Voice*, depicting a white fox terrier listening intently to a phonograph's horn. The painting originally showed an Edison-Bell cylinder phonograph, but the dog's owner painted over it to display a Victor machine. The next year, Johnson trademarked the slogan and used it on his machines, recordings, and advertisements. Nipper the dog became famous worldwide. Johnson changed the name of his company to the Victor Talking Machine Company. He was now a millionaire and president of a company encompassing twelve city blocks. At this time, Johnson, wife Elsie, and their only child, Fenimore, were living in Merion, Pennsylvania.

Johnson continued to perfect his machines. Fidelity improved, and records now could be played 125 times rather than only a few. He developed a process to create multiple copies from an original. In 1906, he introduced the Victrola phonograph, with beautifully designed wooden cabinets that owners could proudly display in their homes. The horn was placed inside a large floor cabinet and could be folded downward. Two doors in front covered the horn. Owners could control the volume with the doors by opening or closing them, or leaving them partially open. The patented name Victrola applied to only machines with internal horns, but eventually Victrola was synonymous with any phonograph. In 1913, the first electric motor was introduced; this eliminated all hand-cranking. Although installed on the Victrolas, they were referred to as Electrolas.

Johnson understood that his customers cared what they listened to on recordings. Johnson and partner Leon Douglass signed famed virtuoso and metropolitan opera star Enrico Caruso to a recording contract. The company sold millions of his recordings. More artists recorded, and Johnson and Douglass implemented a royalty system whereby the artists were compensated for each record sold. The company doubled profits between 1901 and 1903. Profits doubled again in 1905, and again in 1907. The emerging recording industry, under Johnson and Douglass's guidance, flourished because of careful attention to manufacturing and marketing. Sales of the Victor Talking Machine Company, particularly the Victrolas, skyrocketed and Johnson and Douglass became enormously wealthy. The company also went global, with operations in Canada, Japan, South America, and England, further extending the influence of the two men.

Johnson realized the impact the newly introduced radio would have before it happened. In 1927, he and Douglass sold the company to investment bankers, the J. and W. Seligman and Company. The firm then sold the company to the new Radio Corporation of America (RCA), which eventually became the RCA Victor Company. Now comfortably retired with about $25 million, Johnson purchased *Caroline*, a plush yacht that launched in Maine in 1931. He also indulged in an expensive art collection.

One of Johnson's most interesting hobbies was collecting memorabilia of Lewis Carroll's 1865 novel *Alice's Adventures in Wonderland*. Johnson acquired several first editions, and he was even photographed with Alice Liddell Hargreaves, who was the author's inspiration for the book. Johnson purchased the original manuscript of *Alice's Adventures Under Ground* (1864), which he proudly displayed in the White House at the invitation of President Calvin Coolidge.

As a wealthy retiree, Johnson continued his philanthropic ways, establishing an $800,000 endowment at Pennsylvania University, the E. R. Johnson Foundation for Medical Physics (now the Department of Biochemistry and Biophysics). Johnson was a benefactor to the Free Library and Deaconess Home in Camden, the Community Church in Dover, Delaware, the Merion War Tribute House, and the Moorestown Community House in New Jersey. In 1932, he donated his yacht to the Smithsonian Institution to conduct marine exploration of the Caribbean region of the West Atlantic Ocean. His crew of forty-two men and an additional $50,000 funding allocation were included. As part of the agreement, Johnson housed his family and friends and their families in the first-class cabins. Former colleague Leon Douglass and his family joined him on the expedition.

Despite his many professional successes, philanthropic contributions, and vast wealth, Johnson suffered from depression. In poor health for many years, he died of a heart attack at his home on November 14, 1945, in Moorestown.

EARLY VICTROLA PHONOGRAPHS

The primary external components of Eldridge R. Johnson's early Victrola phonographs are the cabinet, platter, horn, sound box, sound box tube, pivot, stylus bar and stylus (needle), thumbscrew, and tonearm. The internal, acoustical energy-producing components are the diaphragm, gasket, support springs, and pivot. The stylus apparatus is located just below the gasket and support springs.

Early Johnson machines were based on Emile Berliner's flat-disc concept. The discs revolved at 78 revolutions per minute. The needle moved side to side in a lateral-cut method. The stylus tracks in the grooves, which contain the acoustical signals, and is secured with a thumbscrew. The revolving record, along with the lateral movement of the stylus, sends vibrations consisting of both frequency and amplitude information of the audio signal to the sound box. The sound box consists of a mica diaphragm. In turn, the diaphragm vibrates, moving the air column into the hollow tonearm. Mechanical energy is converted into acoustical energy in the tonearm and flows into the horn, producing sound waves for listeners.

The diaphragm is similar to a membrane that stimulates the air column in the tonearm. The diaphragm is held in place by a gasket around the edges that prevents it from moving very much on the perimeter but allows the center to move freely. Since the motion is not distributed evenly over the surface of the entire diaphragm, the sound waves produce some distortion. A mechanical governor stabilizes the drive system. One spring motor will play an entire side of a twelve-inch disc without further cranking. An external horn is attached. The 1906 Victrola's internal horn, which was housed within the floor cabinet, required inverting the tonearm elbow in order to funnel the sound into the horn.

The early design of the gramophone required the tonearm, sound box, and horn to all move across the disc simultaneously, adversely affecting the sound. After some experimentation, a newer design was implemented using a rigid tonearm and sound box that moved across the record together while the horn remained fixed in place. A pivot joint between the tonearm and the horn separates them. This change produced notable improvements in sound quality. The basic principles of operation remained essentially the same for Victrolas until the electrical pickup arrived in the late 1920's.

The market for Victrolas steadily increased throughout the early 1900's because of Johnson's creative and expensive advertising program. The historic Caruso recordings brought significant recognition to the burgeoning industry of commercial recording. Gradually, competitors began to somewhat limit Victor's hold on the industry, but Johnson's domain remained secure. The introduction of parlor cabinetry to Victrolas signaled the arrival of designer phonographs. Phonographs were now a household necessity.

IMPACT

Johnson epitomized the self-made man. A product of trade schools and apprentice training, he endured great hardships in his quest to fulfill his life's ambitions. His invention of the spring-driven motor for gramophones provided the link needed to give birth to the recording industry. His steadfast commitment to product excellence and shrewd business dealings provided the impetus to generate an entire new industry—the recording industry. In a twelve-year period, his small shop encompassing seventeen square feet expanded to a complex of fifteen acres, and the company's income increased from $10 a week to $30 million a year. Perhaps more than any other single individual, Johnson was responsible for establishing and advancing the mass production of entertainment in its early stages, beginning with a limited number of consumers until it transformed into today's multimedia empire. The enormous success of RCA Victor can be attributed to the efforts of Johnson.

Once his fortune was made and his ambitions were satisfied, Johnson used his prosperity to benefit society. He generously donated large sums of money and volunteer time to organizations and his communities. His philanthropic commitments culminated with his gift of the Eldridge R. Johnson Park, a prestigious, cultural state and federal historic landmark in the city of Camden. The park serves as a fine arts center for Rutgers University and the surrounding community and represents the cultural and industrial history of Camden.

—*Douglas D. Skinner*

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See also: Emile Berliner; Lee De Forest; Thomas Alva Edison; Peter Carl Goldmark.

FREDERICK MCKINLEY JONES

American engineer

Of more than sixty patents granted to Jones, forty were related to his system for mobile refrigeration. Other inventions include a ticket-dispensing machine, self-starting gas engine, starter generator, and thermostat and temperature control system.

Born: May 17, 1892; Cincinnati, Ohio
Died: February 21, 1961; Minneapolis, Minnesota
Primary field: Electronics and electrical engineering
Primary invention: Mobile refrigeration

EARLY LIFE

On May 17, 1892, Frederick McKinley Jones was born in Cincinnati, Ohio, to John Jones, an Irish American railroad worker, and an African American mother who abandoned the family soon after Frederick's birth. Wanting his son to receive an education, John placed him in the care of the priest at St. Mary's Catholic Church, Father Edward A. Ryan, who gave the boy odd jobs to do and took an interest in helping him develop his amazing mechanical aptitude. Jones was orphaned at age nine.

Jones left the rectory at age eleven to go to Cincinnati and work at the R. C. Crothers Garage. Though Jones was hired to keep the garage clean, his employer noticed his unusual aptitude and allowed him to work full-time as a mechanic when he turned fourteen, the minimum age to work legally in Ohio. Soon, Jones became a foreman. Meanwhile, he developed a keen interest in auto racing and helped build racing cars. He relocated to Minneapolis, Minnesota, where he did janitorial and maintenance work at a hotel. A guest offered him a job maintaining and repairing the machinery and automobiles on a huge farm in the town of Hallock.

When the farm was sold, Jones remained in Hallock for the next eighteen years except for a stint in the U.S. Army's 809th Pioneer Infantry in France during World War I. His unusual mechanical skill was soon noted and his services requested by various military camps. In a short time, he was promoted to sergeant, a rank rarely accorded an African American soldier at that time. Having done some correspondence study in electrical engineering, he taught classes in electrical circuitry. After his discharge, Jones returned to Hallock, where he became actively involved in community affairs, race-car driving, and inventions. In 1946, after Jones had relocated to Minneapolis, he married. He and his wife, Lucille, lived in an apartment over the Thermo King plant.

THE MODEL A TRANSPORT REFRIGERATION UNIT

Frederick McKinley Jones was the first person to invent a workable mechanical refrigeration system for trucks. When Jones heard about a conversation between a farmer and his employer, Joseph A. Numero, in which the farmer recalled how he had suffered great losses of food because of spoilage during long-distance shipping, Jones determined to find a way to end such waste. He began assembling various odds and ends of machinery that would provide refrigeration. When he attached his finished product to a truck and testing showed it to be successful in providing the needed cooling, the first mechanically refrigerated truck was born.

In addition to developing the refrigeration itself, Jones faced the technical challenge of making a structural frame and the necessary refrigerant tubing connections to ensure that the system would be able to withstand the constant vibration on the road. He met the challenge by applying what he had learned years earlier when he designed racing cars to resist shock. A four-cylinder gasoline engine was used to drive the refrigeration compressor, and a starter-generator-flywheel was used for the engine. The unit was controlled by a thermostat that was installed inside the truck trailer. When all the equipment was put into a cabinet that was hung from the floor of the trailer, the unit weighed more than a ton. The trailer remained cool, but the unit was rather inefficient, so Jones redesigned it, reducing the weight by four hundred pounds. When it became evident that moisture and road debris were damaging the under-slung unit, Jones again redesigned the unit, coming up with a 950-pound nose-hung version. The system would be adapted for use in railway cars as well as in ships. After Jones received a patent for the system on July 12, 1940, Numero formed a new company, the U.S. Thermo Control Company, later Thermo King, with Jones as his partner.

Jones's invention of the Model A transport refrigeration system changed Americans' eating habits. No longer did they have to rely on canned foods; the invention ushered in the use of frozen foods. The large supermarket came into being, and the restaurant industry profited from increased availability of fresh foods from anywhere in the country, all year round.

LIFE'S WORK

Despite having a limited formal education, Jones displayed an amazing aptitude for working with all kinds of mechanical things and had an inventive mind. After enlisting in the Army during World War I, he quickly demonstrated his prowess as a mechanic. In addition to repairing military vehicles, he fixed X-ray machines and worked with electrical wiring. After his return to Hallock at the end of the war, Jones wasted no time in further developing his inventive genius. Among the numerous odd jobs that he did, Jones served as a chauffeur for doctors making house calls during the winters. When it became difficult to drive through the snow, he remained undaunted: He attached skis to an old airplane body and attached an airplane propeller to a motor, producing an effective, if unconventional, "snowmobile." In a conversation with a doctor on one occasion, the physician was bemoaning the fact that patients had to come into his office to get X-ray pictures taken, so Jones designed a portable X-ray machine that the doctor could take with him when he made house calls.

Unfortunately, during these earlier years of invention, it did not occur to Jones to have his inventions patented; thus, he saw other inventors become wealthy from their protected versions of various machines and devices. In the late 1920's, he designed a ticket-dispensing machine for movie theaters that would automatically dispense tickets and change. This time, he applied for a patent on the device, which was granted in 1939. About the same time, he found a way to convert silent movie projectors into talking projectors, attracting the attention of his future partner, Joseph A. Numero, who hired him to improve the sound equipment made by his firm, Cinema Supplies, Inc. Amazingly, Jones worked with scrap metal to make the parts needed to deliver a sound track to the video, and he worked with the device to stabilize and improve the quality of the picture.

By the 1930's, Jones was perfecting a system to provide a mechanical refrigeration system for long-haul trucks and railroad cars that would eliminate the risk of food spoilage. This system would later be adapted for use in other types of food carriers such as ships. Jones received a patent for his vehicle air-conditioning device in 1940, and Numero established the U.S. Thermo Control Company (later Thermo King) in Minneapolis.

During the 1940's, Jones continued to invent devices related to refrigeration and air-conditioning in addition to other types of devices. In the area of refrigeration technology, he invented a removable cooling unit for compartments in 1943 as well as an air-conditioning unit in 1949. During the early to mid-1940's, he received a patent for a self-starting gas engine. In later years, Jones worked on improving and adapting his inventions. In 1949, he patented a starter generator for cooling gas engines. The next year, he developed another two-cycle engine; in 1958, a combustion engine device.

During World War II, the U.S. government used Jones's portable air conditioner to preserve blood serum and medicines. In 1944, he was inducted into the American Society of Refrigeration Engineers, the first African American to receive such an honor. This honor was especially meaningful in the light of Jones's limited formal education. During the 1950's, the Department of Defense and the Bureau of Standards sought his services as a consultant.

Jones continued to improve on existing items and invent new ones when he saw a need. His final patent was granted on February 23, 1960, almost exactly a year before his death from lung cancer in Minneapolis. In 1991, Jones and his business partner, Joseph Numero, were posthumously awarded one of the highest honors available to an inventor, the National Medal of Technology. President George H. W. Bush presented the medals to their widows in a ceremony held in the Rose Garden of the White House in Washington, D.C. In 2007, Thermo King, which had become a multimillion-dollar international corporation, dedicated a research and development center in Bloomington, Minnesota, in honor of Jones.

Impact

The sheer number and diversity of patents acquired by Jones is astonishing. At least forty of his more than sixty patents were related to refrigeration. His technology literally revolutionized the distribution methods for transporting food and other perishables over long distances. Since his innovations in refrigeration made fresh produce available year-round to people living anywhere in the United States, his work changed the way Americans planned meals, as a wide variety of out-of-season foods were made available in both fresh and frozen form. His work in refrigeration also facilitated the development of international markets and resulted in the creation of frozen-food and fast-food industries as well as container shipping.

Jones's inventions in refrigeration were not limited to food products. During World War II, a modified version of his portable air conditioner allowed the U.S. military to preserve blood serum and medicines so that they could be parachuted to troops behind enemy lines. Nor was the impact of Jones's technological genius limited to the field of refrigeration and air conditioning: The movie industry was forever changed after Jones devised a way to adapt silent movie projectors so that they could play back recorded sound, thus introducing the "talking picture."

—*Victoria Price*

Further Reading

Brodie, James Michael. *Created Equal: The Lives and Ideas of Black American Innovators*. New York: William Morrow, 1993. Arranged chronologically, this book profiles more than sixty African American innovators and inventors, beginning with slave inventors and moving through to those in the modern era. Contains a section on Jones's life and inventions.

Sluby, Patricia Carter. *The Inventive Spirit of African Americans: Patented Ingenuity*. Westport, Conn.: Praeger, 2004. Using a historical approach beginning with African creations, the book moves on to inventions made during the period of slavery in the United States, treating both enslaved and free persons of color. Notes inventions by African Americans that were important to the war effort during World War I and the "balm" that the Civil Rights era afforded African Americans in terms of being able to demonstrate their skills and creativity. Jones is included in several appropriate sections of the book. A lengthy appendix contains a roster of African American patentees from 1821 through the mid-1990's.

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See also: Clarence Birdseye; Richard G. Drew; Charles F. Kettering; Earl S. Tupper.

PERCY LAVON JULIAN

American chemist

Julian synthesized a number of important drugs from plants, including cortisone, used in the treatment of arthritis, and physostigmine, a glaucoma medicine.

Born: April 11, 1899; Montgomery, Alabama
Died: April 19, 1975; Waukegan, Illinois
Primary field: Chemistry
Primary inventions: Physostigmine sythesis; cortisone sythesis

EARLY LIFE

The grandson of a former slave, Percy Lavon Julian was the son of James Julian, a railway mail carrier, and Elizabeth (née Adams) Julian, a schoolteacher. He and his two brothers and three sisters grew up in a household that valued education. In fact, Julian's two brothers later became physicians, and all his sisters went on to earn master's degrees.

After finishing the eighth grade, Julian enrolled at the State Normal School for Negroes, a private school in Montgomery, Alabama. Upon graduating in 1916 first in his class, he was admitted to DePauw University in Greencastle, Indiana. Julian had to take remedial classes at night for the first two years, but he graduated in 1920 as class valedictorian and a member of Phi Beta Kappa. Julian wished to continue on to graduate school but was discouraged from pursuing that path because of potential racist sentiment. Instead, he taught for the next two years at Fisk University, an African American college in Nashville, Tennessee.

Through an Austin Fellowship, Julian went to Harvard University, where he obtained a master of arts degree in 1923. While his record clearly warranted a teaching fellowship, it was denied, and he spent the next three years in various assistantships seeking the elusive doctoral degree. Finally, in 1926, he began teaching at West Virginia State College. In 1928, he moved to Howard University in Washington, D.C. The following year, he received a Rockefeller Foundation grant, which allowed him to continue his studies at the University of Vienna.

Julian had kept up with the rapidly growing literature concerning the synthesis of natural substances. In Vienna, he studied with the eminent Austrian chemist Ernst Späth, who was conducting fascinating research on the preparation of nitrogen-containing drug molecules called alkaloids. After two wonderful years filled with music and a great deal of serious chemistry, Julian received a Ph.D. in 1931. Späth characterized Julian as "an extraordinary student, the likes of which I have never had before in my career as a teacher."

Percy Lavon Julian, right, and a former student examine a hormone product at the Glidden Company plant in Chicago. (AP/Wide World Photos)

LIFE'S WORK

While Julian was studying in Vienna, he became aware of the great potential of soybeans as a source of steroids. The compounds from this source were to play a central role in his fame as a chemist and inventor. When he returned to Howard University, however, he turned his attention to the synthesis of an alkaloid called physostigmine. This compound is used to treat glaucoma, a condition that can lead to blindness if left untreated. After only two years, Julian left Howard and returned to DePauw.

Over the next three years, Julian

SYNTHESIZING HUMAN HORMONES

In 1936—after being rejected for a position with the Institute of Paper Chemistry because he was black—Percy Lavon Julian became director of the Soya Products Division at the Glidden Company in Chicago. He would soon be the first to synthesize physostigmine, a natural product of some plant sterols, which would become a therapeutic drug to treat myasthenia gravis, glaucoma, Alzheimer's disease, and drug overdoses. He also laid a foundation for the synthesis of human hormones—such as progesterone, testosterone, cortisone, and other steroids—from plant sterols. The wide availability of such compounds and their use in pharmaceuticals would revolutionize medicine.

To appreciate Julian's invention, it is essential to understand the challenge faced by a chemist making a synthetic compound. To synthesize a particular molecule, scientists must understand the exact location of each of the atoms in its structure. Physostigmine, for example, is made up of fifteen carbon atoms, along with three nitrogen and two oxygen atoms. Such an array of atoms can have an astronomical number of possible structures. Of the possible arrangements, only one is the desired molecule. Like all scientists, Julian built on the work of earlier researchers. He knew the structure of physostigmine from the work of earlier chemists. Its synthesis, or preparation from simpler molecules, depends on selecting the proper starting material and adding features using reactions known to produce predictable results. A central problem for the chemist wishing to study a naturally occurring molecule is obtaining a large enough supply from which to synthesize the desired molecule. For example, Julian had isolated a minuscule amount of a valuable sterol called stigmasterol, and he had high hopes of converting it to desirable derivatives. The problem was that soybean oil, the most common source of stigmasterol, contains only about 0.2 percent total sterols, and only 18 percent of that is the desired compound. Julian calculated that it would take more than half a ton of soybean oil to produce two pounds of stigmasterol. However, one day when water leaked into a batch of soybean oil, the by-product, a white solid, gave Julian an idea: By spinning the white solid in an industrial-size centrifuge, he laid the foundation for a process that would produce sterols at a greatly reduced price.

Julian's enormous powers of recall, coupled with his uncanny ability to see connections, turned a large loss into a valuable commodity. A series of patents for expansion and improvement of the process followed. Julian went on to invent inexpensive ways of synthesizing male and female hormones (a precursor to birth control pills), cortisone (leading to drugs for arthritis pain), and other steroids. Overcoming racism (his home was set on fire on Thanksgiving Day in 1950), he established his own company, The Julian Laboratories, for the production of synthetic cortisone and other steroids, eventually becoming a millionaire with more than one hundred patents. Even more important, Julian's work made pharmaceutical products available at prices that ordinary people could afford.

and his chief collaborator, Josef Pikl, a friend from Vienna, published a series of articles in the *Journal of the American Chemical Society* describing the synthesis of physostigmine. Their research was the occasion for great drama, because the same compound was being sought by the eminent British chemist Sir Robert Robinson (winner of the 1947 Nobel Prize in Chemistry). Robinson published the results of his research just as Julian was about to submit his own final paper. On close examination, Julian concluded that Robinson's work was in error and added a note to that effect to his article. In a short time, Julian's work was shown to be correct, and he was recognized for his brilliant contribution to pure organic chemistry.

Julian also discovered that an extract from the calabar bean produced crystals of sigmasterol, which is a key sterol for the synthesis of sex hormones. Recognizing the importance of his discovery, in 1936 Julian wrote to the Glidden Company requesting a five-gallon sample of soybean oil, the chief source of sigmasterol. Glidden's vice president, W. J. O'Brien, happened to learn of this talented young man. Instead of a can of soybean oil, Julian received a phone call, an interview, and the position of director of research of the Soya Products Division. The world's most efficient extraction plant was located in Hamburg, Germany, and a second was being built in Chicago. Julian spent more than eighteen years at Glidden. Under his direction, the Soya Products Division became its most profitable unit.

Julian had the keen ability to find talented people and to see their potential. In his years as a manager, he worked with a number of scientists; together they secured more than one hundred patents. It is equally significant that Julian remained an active scientist as well as a manager. During the years that the business was growing and the practical applications were being protected with patents, he was also a regular contributor to pure chemistry. Before Julian left Glidden to found his own company in 1954, he and his collaborators had published twenty-six articles in the *Journal of the American Chemical Society*. Both alkaloids and steroids were investigated in these researches, an accomplishment that compares favorably with the work that might be expected from an academic scientist working in the laboratory of a major university.

Julian took advantage of unexpected, accidental occurrences. When water leaked into a 100,000-gallon tank of purified soybean oil, he turned the expensive mistake into a method of producing one hundred pounds of mixed sterols per day. In 1940, this represented about ten thousand dollars per day for the Glidden Company. Only Julian could imagine what use could be found for such a huge amount of mixture. Soon he was employing ozone, which had been considered far too dangerous for such large-scale use, to devise an efficient synthesis of progesterone, making that compound available in quantity for the first time.

In 1954, Julian left Glidden to found his own Julian Laboratories in Chicago and Laboratorios Julian de Mexico in Mexico City. He had shown that the use of wild yams was the most efficient way to produce cortexolone, or Substance S, a compound that differed from cortisone by one oxygen atom. He and his associates devised a way to introduce the necessary oxygen atom to Substance S to produce cortisone. This synthesis significantly reduced the price of cortisone, making the pain-relieving drug available to arthritis sufferers.

In 1973, Julian was elected a member of the National Academy of Sciences, an honor considered second only to a Nobel Prize. In 1990, Julian and George Washington Carver became the first African Americans elected to the National Inventors Hall of Fame. Julian died on April 19, 1975.

IMPACT

Julian represents the perfect blend of a serious scientist who explores the details of nature and the practical man of action, who applies those details for the direct benefit of his fellow human beings. His efficient synthesis of cortisone made this important arthritis drug available for the first time to millions of people. The other steroids he prepared in cost-effective processes also had medicinal benefits.

Under Julian's direction, the Glidden Company produced a variety of useful products. Julian created a food supplement that was stabilized against rancidity, edible emulsifiers used in liquid shortening, and animal feeds. His leadership led to the creation of the first plant to isolate and produce pure vegetable protein on a large scale. Just before World War II, Julian devised a soy-derived product called Aero-Foam, used to extinguish oil fires.

As significant as his scientific and industrial accomplishments are, Julian should also be remembered for his extraordinary talent for finding and supporting the very best collaborators. While he was known for his intense work ethic, he would never have been able to accomplish so much without the dedicated support of his fellow scientists.

—*K. Thomas Finley*

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See also: George Washington Carver; Carl Djerassi; Gertrude Belle Elion; Max Tishler.

BOB KAHN

American computer scientist

Kahn, along with Vinton Gray Cerf, developed TCP/IP, the system of protocols used to transmit information over the Internet. With this system, various networks could communicate with one another. For more than twenty-five years, Kahn worked to advance the Internet, helping to transform it into the interactive system it is today.

Born: December 23, 1938; Brooklyn, New York
Also known as: Robert Elliot Kahn (full name)
Primary fields: Communications; computer science
Primary invention: Transmission Control Protocol/Internet Protocol system

EARLY LIFE

Robert Elliot Kahn was born in Brooklyn, New York, in 1938. His father was trained as an accountant and a public school administrator in New York City. Kahn was an outstanding student in school, and he participated in sports and played the piano. Nevertheless, he still had a lot of idle time, so he often worked on puzzles. He could look at a puzzle, look away, and solve it in his mind without looking back. Kahn put many of these activities before his studies, as school work seemed easy to him.

Kahn attended Queens College for two years and the City College in Manhattan for three years. He was finally challenged academically in science and mathematics at Queens College. He initially majored in industrial engineering, then chemical engineering, and finally graduated in 1960 with a degree in electrical engineering.

In the summer while he was at the City College, Kahn worked at Bell Laboratories, where he learned about the telephone traffic system. His mathematics background prepared him for telephone engineering, and he also learned a common computer language, FORTRAN, to use on International Business Machines (IBM) mainframe computers. One of the more important parts of his tenure at Bell Labs involved observing how modeling and analysis methods of telephone operations could be used in various other situations.

In 1960, Kahn received a fellowship from the National Science Foundation to attend graduate school at Princeton University. For his Ph.D., he worked on several practical mathematics problems that he applied to understanding sampling signals and using bandwidth in better ways. He received his Ph.D. in 1964. That year, he became an assistant professor at the Massachusetts Institute of Technology (MIT). There he taught courses in probability and information theory for several years.

LIFE'S WORK

In 1967, Kahn took a leave from MIT to work at the small consulting firm Bolt Beranek and Newman (BBN). From 1967 to 1971, he helped design and build the first computer network, called the Advanced Research Projects Agency Network (ARPANET), a U.S. Department of Defense network that used packet switching to send data between mainframe computers. Packet switching was a new communications method that transferred information electronically by breaking it up into small pieces called packets. Each packet would travel across a computer network and be reassembled at the receiving end. The implementation of sending data between different mainframe computers (there were no personal computers then) was a completely new approach. First, it required an electronic link between the computers with a way to transfer the data in an orderly manner. Second, a common language had to be used so that different computers could understand one another.

The packet-switching method used by ARPANET (the precursor of the Internet) broke up the message into packets of data using a minicomputer called an Interface Message Processor (IMP). Each packet had the address to where it was being sent and sequence information so that each packet could be reassembled to form the final message when it reached the IMP at its destination. The packets could move through the network using different paths and even reach the destination in the wrong order, so the receiving computer had to assemble the packets in the correct order. A method was devised to have a packet resent if it was not received.

The first four sites on the ARPANET were at three different universities in California and at one university in Utah using IMPs linked with high-speed phone lines. By the early 1970's, the ARPANET had grown to fifteen connected sites, demonstrating that the packet-switching technique was reliable. In 1972, Kahn organized the International Conference on Computer Communications (ICCC), held in Washington, D.C., and encouraged programmers to write applications and documentation for the ARPANET to demonstrate its use. Forty computer terminals were set up at the conference to demonstrate the potential of networking computers. The ICCC excited people about the use of networking for a variety of purposes in such fields as education, medicine, research, and business. ARPANET use surged after the conference, and such networking continued to increase dramatically over the following years. However, in order for a true internetwork to be realized, another step was needed to be able to connect computer networks with different individual hardware and software configurations.

In 1972, Kahn began working for the U.S. Defense Advanced Research Projects Agency (DARPA), where he worked on a satellite packet network. He also established a radio packet network. These networks worked at different speeds and had a different number of packets than did the ARPANET. Kahn was motivated to make these different networks compatible with one another, and he began to work with computer scientist Vinton Gray Cerf on the problem. Together they designed Transmission Control Protocol/Internet Protocol (TCP/IP), a system of protocols that enables computers to communicate with one another. The IP contains the address to identify the host computer and the destination computer. The TCP ensures that the stream of packets are transferred in a reliable way through the network so that no data is lost.

Kahn became the czar of grant giving for computing in the latter part of the 1970's. For instance, he issued grants to Stanford University to develop a large-scale integrated circuit. Such work soon led to the use of the TCP/IP system in UNIX workstations so that smaller networks could more easily be integrated into the Internet. University researchers and students were among the first to use this system.

Kahn left DARPA in 1985 to start the Corporation for National Research Initiatives (CNRI), a nonprofit organization that works to make the Internet more useable. CNRI built some of the first Internet browsers, MCI Mail (the first commercial application on the Internet), and digital libraries. In 1989, CNRI showed how the MCI Mail system worked, allowing other e-mail services to quickly develop and leading to an explosion in e-mail use.

Though at first TCP/IP did not seem very important, it would become the standard protocol suite of the Internet. Both Kahn and Cerf later received numerous awards and honors for this development. Kahn is the recipient of the Presidential Medal of Freedom, the AFIPS Harry Goode Memorial Award, the Alexander Graham Bell Medal, the IEEE Third Millennium Medal, the Secretary of Defense Civilian Service Award, the National Medal of Technology, and the Turing Award. He was inducted into the National Inventors Hall of Fame in 2006.

IMPACT

As the coinventor of the TCP/IP system, Kahn helped create the now standard system of protocols used to connect computer networks over the Internet. TCP/IP is the lan-

TRANSMISSION CONTROL PROTOCOL/INTERNET PROTOCOL (TCP/IP)

Bob Kahn worked with Vinton Gray Cerf to create a system whereby computer networks with different individual hardware and software configurations could communicate with one another. Kahn knew very well the overall problems involved with networking, and Cerf was best at implementing the small details into different systems. Kahn and Cerf knew enough about each other's expertise to be able to find problems with each other's logic. They decided that no changes would be made within individual networks in order for them to connect with others. This was reasonable, since changing all networks would be incredibly difficult. Instead, Kahn and Cerf decided to put the Interface Message Processor (IMP) minicomputer (now called a router) between networks to change the size of packets (small pieces of data) or the number of packets that each network needed at the packets' destination. They called this system the Transmission Control Protocol, later known as TCP/IP. In the TCP/IP system, the Internet Protocol (IP) ensures only that the packets arrive at the computer destination. TCP focuses on reliable delivery of data, deals with lost or corrupted packets, and reassembles the packets at the destination. Kahn and Cerf announced their idea for TCP/IP in 1973 and published on the topic in 1974. As Kahn and Cerf worked on their ideas for their paper, Cerf had graduate students at Stanford University implementing these ideas on a minicomputer that could be used, if necessary, to modify Kahn and Cerf's approach to solving this problem.

In 1977, Kahn and Cerf set up a network that transmitted data through three separate networks—Packet Radio Net, ARPANET, and SATNET. The packets of data were transmitted 94,000 miles, from the San Francisco Bay Area to Massachusetts, then to Norway and London, and finally to the University of Southern California's Information Sciences Institute. No information was lost in this transfer. Although this was the first demonstration of the TCP aspect of the new protocols, the landmark event—a pivotal step in the development of the Internet—went largely unnoticed.

guage by which computers around the world "speak" with one another. Indeed, this language has allowed the Internet to develop into the powerful forum it is today.

Kahn had the insight to inspire and organize others to work to build the Internet in the 1970's. He continued to develop the Internet for decades after he helped to establish the TCP/IP system.

—Robert L. Cullers

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See also: Tim Berners-Lee; Vinton Gray Cerf; Alan Mathison Turing.

DEAN KAMEN

American entrepreneur

Kamen is best known for his Segway PT (personal transporter), a self-balancing, electric-powered pedestrian scooter. With the invention of such devices as the AutoSyringe, HomeChoice, iBOT, Luke Arm, and the Slingshot—among more than 107 patents—Kamen is said to be one of the most accomplished inventors in the world.

Born: April 5, 1951; Rockville Centre, New York
Primary fields: Electronics and electrical engineering; mechanical engineering; medicine and medical technology
Primary inventions: Segway PT; iBOT

EARLY LIFE

Dean Kamen was born in Rockville Centre, New York, on April 5, 1951, to Jack, an illustrator for *Weird Science* and *Mad* magazine, and Evelyn, a high school teacher. As he later recounted, he was interested in gadgetry from an early age. By the time he was five years old, he was devising his first gadget: one that allowed him to make his bed without having to move repeatedly from side to side to do so.

However, the young Kamen was not so interested in school. By the time he was in junior high, he found rote learning distasteful, was averse to traditional conventions of education (and being told what to do), and decided that test-taking was little more than the errand of a fool. He challenged many of his mathematics and physics teachers, heckled others, and opted for reading on his own—such works as Isaac Newton's *Principia* (1687)—rather than doing homework.

Through junior high and high school, Kamen was only an average student, but at home the teen was prodigious. Working with transistorized electronics, he designed, built, and redesigned audiovisual control systems, and at sixteen he began landing contracts to install his works at the Four Seasons Hotel, the Hayden Planetarium in Manhattan, and the Museum of the City of New York. The teenager was also commissioned to automate the New York Times Square ball to drop on New Year's

Eve. Though still in high school, Kamen was taking home earnings that nearly matched those of his mother and father combined: $60,000 a year.

THE SEGWAY PT

Electromechanical engineer Dean Kamen is best known for his Segway PT, which has influenced culture and will likely continue to do so in the future. Kamen's most famous invention had a sketchy start: When he introduced the Segway on ABC's *Good Morning America*, the initial reception was bland at best, one of disappointment and chagrin at worst. This is because of what occurred before Kamen unveiled his machine.

Kamen worked on the Segway for ten years, spending millions of dollars in the process. He also kept it a closely guarded secret. Only a select few technicians and fellow engineers—and one privileged reporter, Steve Kemper, who was called by Kamen to observe and document—were made privy to what was to be "the world's first self-balancing human transporter," one that would be energy-efficient and able to share the sidewalks with pedestrians. The Segway HT that first clocked at 17 miles per hour was code-named "Ginger," but the device was known as "It" to the public. The device was rumored to be a technological marvel that would revolutionize transportation. Intrigue multiplied as word got out that Apple Computer's Steve Jobs had deemed it an invention as important as the personal computer. Segway financial backer John Doerr stated that entire cities would be designed around "It."

When finally unveiled, however, the Segway turned out to be just a scooter—one with the back cut off. It was misrepresented in public relations stints, and it was priced at $4,950. Marketing had projected that 31 million units would sell in the first ten to fifteen years, but only 23,500 sold in the first six years. Recalls were a nightmare: Segway riders could stay on as long as the machine was moving, but users fell off as the batteries wore down. In 2006, a software glitch forced a recall of 24,000 units. Limitations on where Segways were allowed also destroyed the dream of making the device universally accepted: In a number of cities, people were forbidden to use them on sidewalks. In 2004, they were banned from Disney-owned parks.

Doerr recruited a new chief executive officer, James D. Norrod, to do some damage control. Norrod studied the technology and consumers and came up with a decision to increase Segway's utility by going to a second prototype on file and adding two more wheels—though the new version strayed from Kamen's original vision. In response, Kamen brought out a larger, more capacious version, added a price tag of $10,000, and dropped the price of the original Segway to $3,000. Police officers, security guards, postal workers, park rangers, corporate fleet personnel, tour guides, and military personnel and veterans are making more and better use of the Segway. While the jury may still be out, Kamen has said that he will let history determine whether or not his ideas are important.

LIFE'S WORK

Though he preferred working on inventing, Kamen did finish high school and in the early 1970's went on to study at Worcester Polytechnic Institute (WPI) in Massachusetts. At the same time Kamen was attending WPI, his brother Barton was studying medicine at Harvard. There, Barton discerned the problem of patients who in their need for continuous, twenty-four-hour treatment had to visit the hospital for their medications. Kamen worked on the problem until he came up with the answer: a portable drug infusion pump patients could wear that administered set doses of medication and that freed the people from having to go to the hospital every time they needed a treatment.

By 1976, Kamen had stopped his five-year college studies at WPI and founded his first company, AutoSyringe, after the same name as his infusion pump. AutoSyringe was housed at its birthplace, Kamen's parents' home. There, when the basement got too crowded for production, Kamen took it upon himself to send his parents on a cruise, commission an architect, and hire a crew to raise the house on stilts and expand the basement to accommodate manufacture and sales. Two years later, Kamen demonstrated his first infusion pump to an applauding medical and scientific community. In 1982, the reputed maverick inventor sold the company and product rights for $30 million.

That same year, Kamen founded DEKA Research and Development, to offer inventor-for-hire services. He set up shop in Manchester, New Hampshire, where Kamen moved in 1988. In 2009, the company employed nearly two hundred engineers, technicians, and machinists. In 1989, he founded FIRST (For Inspiration and Recognition of Science and Technology), an organization that sponsors robotics competitions for young people and encourages them to enter careers in science and technology. In 1993, Kamen invented HomeChoice, a portable kidney dialysis machine. In 1995, he invented iBOT, a revolutionary robotic mobility system designed with three pairs of wheels, sensors, gyroscopes, and servomotors that give the "wheelchair" a balance mode function that allows it to raise, as if on its back haunches, enabling the user to virtually stand and climb curbs and stairs. In his eight-year, $50-million designing process for iBOT, Kamen later said that he focused on the nuances of mobility, on restoring not only accessibility but also dignity to disabled people. When the first conventional wheelchair users tried the iBOT, Kamen reported, they were in tears.

Yet what has made Kamen both famous and infamous is his invention introduced in December, 2001: Ten years in the making and costing millions of his own money, the Segway came to the attention of the public by way of national television. The self-balancing, electric-powered personal transporter (PT) device was futuristic, innovative, but a disappointment. The product itself was not a failure, but the hype surrounding the device before its release apparently made out the Segway to be much more than it actually was: a personal scooter powered by computer-controlled electric motors and unique in its self-balancing and other capabilities.

Undaunted, Kamen continued to invent devices that do indeed liberate, accommodate, empower, and even save lives: DEKA was commissioned by the Pentagon's Defense Advanced Research Projects Agency (DARPA), to devise such apparatuses as a "controllable launcher," which can launch an urban fighter from the ground into an arc in the air and onto a building rooftop in 1.2 seconds; PowerSwim fins, which give the combat diver underwater speeds of up to two knots; and the Luke Arm (named for the *Star Wars* character Luke Skywalker), a lightweight, brain-controlled prosthetic arm, which, with its fourteen sensors, enables the user to sense and distinguish temperature and pressure without looking. Most notably, Kamen worked on a project to provide developing countries with clean energy and water. In 2003, Kamen and DEKA produced the Slingshot, a nonpolluting, low-power, relatively cheap water-purifying system. It is easily installed and works on a Stirling engine. Unfortunately, Kamen had difficulty finding a commercial manufacturer for the Slingshot.

The upbeat inventor has been awarded for his innovation and influential efforts. After such accolades as the Kilby Award (1994) and the Hoover Medal (1995), Kamen was named to the National Academy of Engineering in 1997 and was awarded the Heinz Award in Technology, the Economy, and Employment in 1998 and the National Medal of Technology in 2000, for his biomedical inventions that have advanced worldwide medical care and for engaging America in the excitement of science and technology. For his invention of the Segway and the infusion pump for diabetics, Kamen was granted the Lemelson-MIT Prize in 2002. His Slingshot project was runner-up in *Time* magazine's "Coolest Invention of 2003." For his invention of the AutoSyringe, Kamen was inducted into the National Inventors Hall of Fame in 2005. He was honored with the United Nations' Global Humanitarian Action Award in 2006, and in 2007 he was listed as one of fifty outstanding leaders on the *Scientific American* 50 annual list of key contributors in science and technology. Kamen has been awarded honorary doctorates from various universities, including Kettering University, in 2001, and Plymouth State University, in 2008.

IMPACT

Kamen has affected the world with his avant-garde vision. The Segway, first mocked for its failure to live up to its hype, has become useful in assisting not only police officers and security guards but also people with mobility problems. Kamen's medical inventions—including the AutoSyringe, the wearable infusion pump for diabetics, and the HomeChoice portable dialysis machine—profoundly changed the lives of those who used the devices. Patients no longer had to go to medical facilities every time they needed treatment. The iBOT has also improved the lives of many wheelchair-bound persons, allowing them to go up and down stairs, step onto and off curbs, and navigate rough terrain—to perform actions that perhaps they had never done before. Kamen has reached out to engage young minds in science and technology with his FIRST program, and his Slingshot water-purifying system has the potential to provide clean water at little cost to people in developing countries. His inventions have changed the way people live and even their quality of life.

—*Roxanne McDonald*

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See also: Helen M. Free; Ashok Gadgil; Willem Johan Kolff; Steve Wozniak.

HEIKE KAMERLINGH ONNES

Dutch physicist

Kamerlingh Onnes was a pioneer in the field of ultra-low-temperature physics. He was the first to liquefy helium, and he discovered superconductivity.

Born: September 21, 1853; Groningen, the Netherlands
Died: February 21, 1926; Leiden, the Netherlands
Primary field: Physics
Primary invention: Helium liquefaction

EARLY LIFE

Heike Kamerlingh Onnes (HI-kuh KAH-mehr-leeng ON-uhs) was the firstborn son of Harm Kamerlingh Onnes, a manufacturer of roofing tiles, and Anna Gerdina Goers. Eventually, Heike had four brothers and two sisters. His maternal grandfather was an architect, and all members of his family were artistically talented. Heike was the only child who was interested in pursuing a career in the sciences, though he maintained a lifelong interest in the arts. His parents were very disciplined and taught him respect for hard work and patience. He was often ill as a child, and he continued to have health problems throughout his life.

Since his father had a stable job in Groningen, Kamerlingh Onnes lived most of his early life in the city of his birth. His secondary education was at the Hoogere Burgerschool in Groningen. Kamerlingh Onnes excelled as a student, particularly in science and mathematics. In 1870, after taking additional classes in classical languages, Kamerlingh Onnes enrolled at the University of Groningen at age seventeen. He was an outstanding student at the university and received an academic gold medal and bachelor's degree in 1871. He also served as student body president there. After two years at Groningen, Kamerlingh Onnes studied for three terms at the University of Heidelberg in Germany, under the direction of Gustav Kirchoff and Robert Wilhelm Bunsen. In 1873, Kamerlingh Onnes returned to Groningen to finish his education. He was appointed as assistant to the director of the Polytechnic School in Delft in 1878, where he began a close professional relationship with Johannes Diderik van der Waals. There Kamerlingh Onnes honed his skills in thermal physics. He received his doctorate with honors in 1879. His dissertation was on "A New Proof of Earth's Rotation."

LIFE'S WORK

In 1881, Kamerlingh Onnes published his first paper dealing with the properties of matter at low temperatures. In 1882, at the age of only twenty-nine, he was appointed professor and chair of experimental physics at the University of Leiden, where he spent the rest of his career. A year later, he was admitted to the Royal Academy of Sciences of Amsterdam. His position made him the director of physics laboratories at Leiden. Kamerlingh Onnes impressed upon all the faculty at Leiden the importance of meticulous measurements, ordering that the motto "Door meten tot weten" (through measurement to knowledge) be placed over each laboratory door. Kamerlingh Onnes also reorganized the physics laboratories into a cooperative venture. Faculty were encouraged to work with one another, and researchers from all over Europe were encouraged to come work at Leiden. Furthermore, he established a central glassblowing shop and machine shop to support research at the institution, rather than each researcher attending to his or her own fabrication needs. Though, being a professor, he was required to teach, Kamerlingh Onnes strongly disliked teaching, preferring his research duties instead. He often persuaded others, especially his friend Hendrik Lorentz, to teach his classes for him.

Five years after coming to Leiden, Kamerlingh Onnes married Maria Adriana Wilhelmina Elisabeth Bijleveld in 1887. Their only child, Albert Harm Kamerlingh Onnes, was born one year later.

In 1892, Kamerlingh Onnes perfected a cascade-type gas liquefaction device to supply his laboratories with liquid nitrogen and oxygen. This device cooled gas in stages, with each stage cooling a different gas to be used in later stages. His gas liquefaction system would be used for decades, and gases are still liquefied today using similar methods.

To further support research efforts at his laboratories and to promote research at other laboratories around the world, in 1901 Kamerlingh Onnes created the Society for the Promotion of the Training of Instrument Makers at Leiden. The training provided by the society taught glassblowers, machinists, and other instrument makers the specialized skills needed to support scientific laboratory research. Leiden-trained instrument makers soon became highly valued throughout all Europe.

By 1906, Kamerlingh Onnes had managed to liquefy hydrogen. James Dewar had liquefied hydrogen eight years earlier, but Kamerlingh Onnes was able to produce liquid hydrogen at a far greater rate than other laboratories at the time. He had been required to create special cryostats capable of keeping the liquefied gas cold. He then turned his sights to helium, the only gas that had not been liquefied. Applying van der Waals's theories to helium, Kamerlingh Onnes calculated that helium could only be liquefied a few degrees above absolute zero. By using techniques similar to those that he used to liquefy hydrogen, he finally succeeded in producing liquid helium, at a temperature of about 4 kelvins, on July 10, 1908. He was the first person ever to liquefy helium. Using his refrigeration technology, Kamerlingh Onnes was eventually able to reach a temperature as low as 0.83 kelvin.

After liquefying helium, he turned his attention to the electrical properties of metals at low temperatures. One theory at the time suggested that electrical conductivity increased steadily as temperature decreased, reaching a maximum value at absolute zero. Another theory, proposed by Lord Kelvin (William Thomson), held that the conductivity would reach a maximum at a temperature above absolute zero, then decrease to zero as the temperature decreased closer to the absolute zero. To investigate which of these theories was correct, Kamerlingh Onnes began experiments with the metal mercury in 1911. To his surprise, he found that the mercury sample's electrical resistance suddenly went to zero at just below the boiling temperature of liquid helium. At first, he suspected an instrumentation short circuit, but repeated experiments repeated his observations. By 1913, he had shown that tin also exhibited a sudden vanishing of resistance at low temperatures. He coined the term "superconductivity" to describe the phenomenon.

The Royal Society of London awarded Kamerlingh Onnes its Rumford Medal in 1912. He was awarded the Nobel Prize in Physics in 1913 for this work in low-temperature physics, including the liquefaction of helium and the discovery of superconductivity. During World War I, Kamerlingh Onnes used his notoriety as a Nobel laureate to work to overcome political differences between scientists and to secure aid for starving children in countries suffering from food shortages.

Kamerlingh Onnes never retired. In the 1920's, he again turned his attention to helium. He observed that its density suddenly increased at a temperature of about 2 kelvins. However, his poor health interfered with his studies. In 1926, after a short illness, he died without completing his work on liquid helium. The phenomenon that he had discovered would later be studied by Pyotr Leonidovich Kapitsa, who would eventually get credit for its discovery and who named it "superfluidity."

Impact

Kamerlingh Onnes was a major figure in the early days of ultra-low-temperature physics. He was the first to liq-

Heike Kamerlingh Onnes. (©The Nobel Foundation)

HELIUM LIQUEFACTION

Many gases can be liquefied through refrigeration using other substances as coolants. However, hydrogen and helium have critical temperatures far below even the freezing points of other substances, so another method is needed to liquefy these gases. (The critical temperature of a substance is the temperature at which liquid and gas are indistinguishable.) Near the end of the nineteenth century, two physicists worked to liquefy these gases: Heike Kamerlingh Onnes, in Leiden, and James Dewar, in London. Dewar succeeded in liquefying hydrogen before Kamerlingh Onnes. By 1908, though, Kamerlingh Onnes had extended upon Dewar's methods to devise his own helium liquefaction system, which he called a "helium liquefactor."

In order to cool these gases, both Kamerlingh Onnes and Dewar used Joule-Thomson cooling. James Johnson and William Thomson (also known as Lord Kelvin) had shown in 1852 that certain gases would cool if allowed to expand adiabatically (occurring without loss or gain of heat) through a porous plug under constant enthalpy conditions. The most important condition that must be met is that the gas must start below a critical temperature, called the inversion temperature. Gases above their inversion temperature would warm if they expand under constant enthalpy, but gases below that temperature cool. For most gases, the inversion temperature is quite high, but for hydrogen it is 202 kelvins (–71° Celsius), and even lower, at 51 kelvins (–222° Celsius), for helium, so these gases must first be cooled by some other means below these temperatures before Joule-Thomson cooling can be used. The inversion temperature of helium is lower than the freezing points of nitrogen and oxygen, so Kamerlingh Onnes and Dewar both realized that liquid hydrogen must first be produced to precool the helium.

The helium liquefaction system that Kamerlingh Onnes built was in essence a series of liquefaction systems, with the helium liquefactor being simply the last step. The process started with a standard cascade refrigeration system to liquefy oxygen. The liquid oxygen was used to cool the hydrogen below its inversion temperature. Kamerlingh Onnes used Johannes Diderik van der Waals's principle of corresponding states to show that the critical point of helium was near 5 kelvins, thus a single-stage Joule-Thomson cooling, such as Dewar was using, would not suffice to liquefy helium. Thus, Kamerlingh Onnes built an iterative system. Helium was compressed, cooled with liquid hydrogen, and then allowed to expand, cooling it further. This colder helium was then used to cool more compressed helium, which was then allowed to expand, producing even colder helium. Through a sequence of such steps, the temperature of the helium could be lowered to the point at which it began to condense as a liquid. Using this system, Kamerlingh Onnes succeeded in liquefying helium on July 10, 1908, becoming the first scientist to do so.

uefy helium, and for nearly fifteen years his was the only facility able to produce liquid helium. His careful work and techniques established a pattern for other researchers to follow when studying phenomena at extremely low temperatures. Furthermore, his refrigeration devices became the standard model for reaching such low temperatures.

Superconductivity, which Kamerlingh Onnes discovered, gave rise to a new subfield of ultra-low-temperature physics. The mechanism by which a substance becomes a superconductor would not be known for many years to come, however. The ability of a material to pass electricity without resistance eventually permitted the development of the most powerful magnets ever constructed. Later work on superconductors would lead other physicists to Nobel prizes of their own over the next century. Superconductors have come to have many important applications in modern technology, particularly through their ability to be used to produce extremely powerful electromagnets.

However, Kamerlingh Onnes's impact on physics extended far beyond simply the field of low-temperature research. He foresaw that science had moved beyond the individual scientist working in his laboratory. Scientific research had become more complex, often requiring teams of researchers. Also, the equipment required by the researchers was becoming more complicated than could be fabricated solely by the researchers themselves. His model of a coordinated research facility with shared support staff became the model of every physics laboratory since that time. His work made the physics laboratory facilities at Leiden the best in the world for low-temperature physics. Even today, those facilities, now called the Kamerlingh Onnes Laboratory, make up a first-class research institution.

—*Raymond D. Benge, Jr.*

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See also: J. Georg Bednorz; Robert Wilhelm Bunsen; Sir James Dewar; William Francis Giauque; Pyotr Leonidovich Kapitsa; Lord Kelvin; Karl Alexander Müller.

PYOTR LEONIDOVICH KAPITSA

Russian physicist

Kapitsa was an extraordinary physicist whose research encompassed such diverse areas as extreme magnetic fields, low-temperature physics, and high-power microwave physics. He was the corecipient of the Nobel Prize in Physics in 1978 for his discovery of thesuperfluidity of liquid helium and for his basic inventions in low-temperature physics.

Born: July 8, 1894; Kronshtadt, Russian Empire (now in Russia)
Died: April 8, 1984; Moscow, Soviet Union (now in Russia)
Primary field: Physics
Primary invention: Planotron

EARLY LIFE

Pyotr Leonidovich Kapitsa (PYOH-tehr lyi-uh-NYEE-duh-vyich KAH-pyih-tsuh) was born on the Russian island of Kronshtadt on July 8, 1894. His father was Leonid Petrovich Kapitsa, a military engineer, and his mother was Olga Ieronimovna (née Stebnitskaia), a folklore researcher. As a boy, he lived in Tsaritsyn (now Volgograd). Following his early education in Kronshtadt, Kapitsa went to study engineering and the physical sciences at the Petrograd Polytechnical Institute. In 1916, while at the institute, he married Nadeshda Tschernosvitova, and later had two children by her.

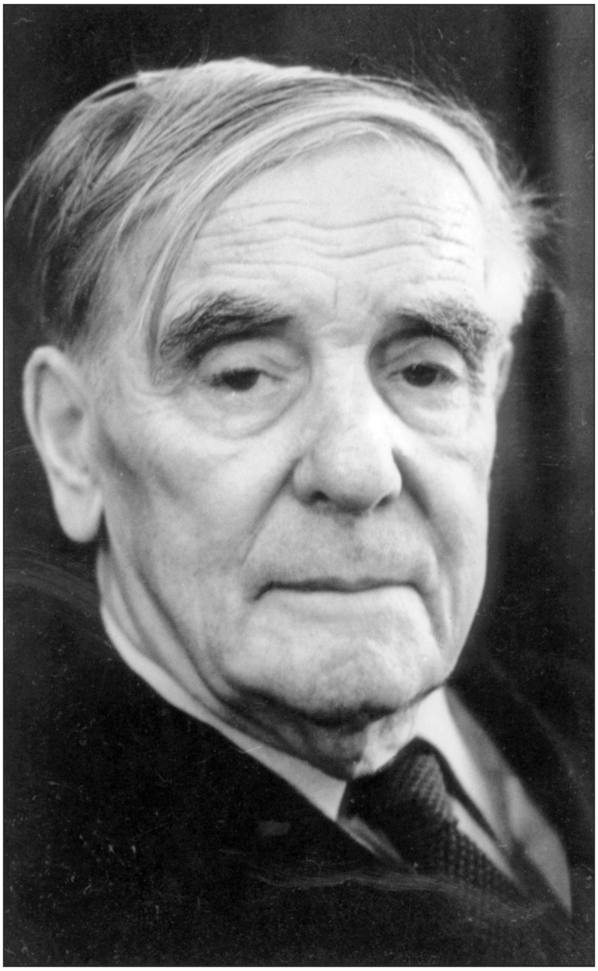
Kapitsa graduated from the Petrograd Polytechnical Institute with an electrical engineering degree in 1918, a year after the Russian Revolution. He then became a lecturer at the institute, which had been renamed the First Polytechnical Institute. Under the new communist control, academicians did not have the same rank, support, and authority as before, and the working environment was strained. Kapitsa's life took a turn for the worse when the 1918-1919 Spanish influenza pandemic swept through Russia. His father, wife, and two children all died. Despite this tragedy, Kapitsa managed to publish several papers during this time. In 1921, he was permitted to leave the country to travel to England as part of a Soviet Academy of Sciences mission. There he met Ernest Rutherford, who persuaded him to stay at Cambridge's Cavendish Laboratory. Kapitsa was awarded a doctorate in physics from Cambridge in 1923.

LIFE'S WORK

In 1924, Kapitsa was made the assistant director in charge of magnetic research at the Cavendish Laboratory and was made a fellow of Trinity College in 1925. At Cavendish, he at first continued work begun at the Polytechnical Institute on extremely powerful magnetic fields. Kapitsa helped to discover that alpha radiation consisted of positively charged massive particles by observing their deflection in a cloud chamber placed in a strong magnetic field. He also discovered a relationship between resistance and magnetic field strength of metals placed in strong magnetic fields. Kapitsa's observations that extreme magnetic fields influenced temperature ultimately led him to begin studies of low-temperature physical phenomena. He became particularly interested in the unusual properties of superconductors and the nature of helium at low temperatures.

In 1927, Kapitsa married Anna Alekseevna Krylova, the daughter of a prominent Soviet mathematician. Together, they had two sons, Sergei and Andrei. Anna Kapitsa routinely traveled with her husband on trips to the Soviet Union from their new home in England.

In 1929, Kapitsa was elected a member of the Royal Society and soon thereafter as a corresponding member of the Soviet Academy of Sciences. Kapitsa soon turned his interest fully to low-temperature physics. By 1932, he had designed an improved helium liquefaction system capable of producing more than two liters of liquid helium per hour. With Rutherford's support, the Royal Society built the Mond Laboratory at Cambridge for low-temperature physics research. Kapitsa served as the director of the laboratory until 1934. He would have remained at Cambridge indefinitely; however, on a routine trip back to the Soviet Union to visit his mother in 1934, the Soviet government canceled his and his wife's passports, effectively prohibiting his leaving the Soviet Union.



Pyotr Leonidovich Kapitsa. (©The Nobel Foundation)

Negotiations between Kapitsa and Joseph Stalin resulted in the former's appointment, in 1935, as director of the newly created Soviet Institute of Physical Problems (now the Kapitsa Institute for Physical Problems). As institute director, Kapitsa worked to secure the equipment built for his low-temperature research at the Mond Laboratory. When his new laboratory was set up using his specially built equipment, Kapitsa once again resumed his low-temperature physics work. In 1938, he announced the discovery of a new state of liquid helium that occurs under conditions colder than 2.17 kelvins. This state of matter is called a superfluid because it is able to flow without viscosity. However, superfluidity is not simply zero-viscosity liquid; rather, it is a different state of matter. For a long time, helium was the only substance known to be capable of undergoing a transition to a superfluid state.

During World War II, Kapitsa's laboratories in Moscow became the primary source for liquid oxygen for the Soviet Union. Kapitsa became head of the Department of Oxygen Industry. Kapitsa's own research turned toward nuclear physics and cosmic rays at this time. At the end of World War II, Stalin appointed Kapitsa to a special research team charged with the development of an atomic bomb for the Soviet Union. However, Kapitsa's personal beliefs and opinions soon put him at odds with the team's political adviser, ultimately resulting in Kapitsa's falling from Stalin's favor. He was removed from the research team, removed as head of the Institute for Physical Problems, and stripped of all his academic rank and privileges. He was placed effectively under house arrest at his home in the Moscow suburb of Zvenigorod from 1946 until after Stalin's death in 1953.

During this time, Kapitsa was unable to continue the research that he had been doing at the institute; however, he was able to construct instruments at his home to study the field of high-energy microwaves. He invented two devices, the planotron and the nigotron, to produce microwaves of far higher intensities than could be easily produced in the laboratory before. Kapitsa also did theoretical work in high-power electronics during this period. Nikita S. Khrushchev, after taking over from Stalin, began to return some of the privileges that Stalin had taken from Kapitsa, though Kapitsa was never fully reinstated to his former positions. Kapitsa continued his studies of high-energy microwaves and plasma physics. From 1955 onward, he served as editor of the *Soviet Journal of Experimental and Theoretical Physics*. In 1957, until his death, Kapitsa was a member of the presidium of the Soviet Academy of Sciences.

In 1964, Kapitsa was permitted to leave the Soviet Union to receive the Niels Bohr International Gold Medal for his work in low-temperature physics. In 1978, he shared the Nobel Prize in Physics with Arno Penzias and Robert Wilson. Kapitsa continued to work until his death, though in his later years his productivity waned. He died in Moscow on April 8, 1984, three months before his ninetieth birthday.

Impact

Throughout his career, Kapitsa demonstrated interest in all aspects of physics. Few other physicists of the twentieth century did such extensive work in so many different areas of physics. His work in low-temperature physics, including his discovery of superfluid helium, was instrumental in the development of that field and led to his winning, with Penzias and Wilson, the 1978 Nobel Prize in Physics. Penzias and Wilson's half of the prize was for their discovery of the cosmic microwave background radiation, which permeates the universe.

Kapitsa spoke out on many social and political issues. He was particularly critical of the Cold War. Though never officially declared a dissident, Kapitsa's outspokenness certainly pushed the limits of what was permitted under totalitarian Soviet control. He was not at all shy about challenging either Stalin or Khrushchev on various matters. That he was able to approach such powerful Soviet leaders and that they tolerated his challenges demonstrated how important he and his work were considered.

—*Raymond D. Benge, Jr.*

The Planotron

Producing microwaves in a controlled fashion was quite difficult until Albert Wallace Hull's invention of the magnetron in 1921. The magnetron uses crossed electric and magnetic fields in a device that resembles a hollow cylinder with a rod down its center and small cavities spaced around its outside. A magnetron can quite efficiently convert electrical energy into microwaves; however, is has certain limitations. To overcome some of these problems, Pyotr Leonidovich Kapitsa invented a related device that was able to produce microwaves at even higher power and precision. Kapitsa described the device as being much like a magnetron that had been cut open and spread out in a plane. Due to the planar nature of the device, Kapitsa called it a planotron.

The planotron consists of a metal plate kept at a voltage above that of the rest of the apparatus. This is the planotron's cathode. At a fixed distance from the cathode are a series of identical and uniformly spaced anodes (conducting pieces kept at a lower voltage than the cathode). The space between the cathode and the anodes is the working space for the planotron, in which the microwaves are produced. The entire planotron must be operated in a vacuum. When the anodes are heated, electrons will try to flow across the space between the anodes to the cathodes. However, in operation, a magnetic field is established perpendicular to the electric field (hence, parallel to the cathode). Electrons moving in a magnetic field move in a circular path. However, electrons moving in the presence of both electric and magnetic fields move in a trochoidal path (the path drawn by a point at the edge of a rolling circle). An alternating electric field is then established between the anodes, with adjacent anodes being of opposite phase. This causes the electrons to move in a path that resembles an epitrochoid.

As the electrons move in their cyclic motion, they gradually lose energy into electromagnetic radiation. The frequency of radiation is determined by the spacing of the anodes and by the alternating field between them. Typical spacings yield frequencies that are those of microwaves. Like the magnetron, the planotron is extremely efficient at converting electrical energy into microwaves, but it is able to operate at far higher power.

Not only can a planotron efficiently convert electrical energy into microwaves, it can also work in reverse, converting microwaves into electrical energy with similar efficiency. Kapitsa wrote about the possibility of using planotrons for wireless transmission of electrical energy. For terrestrial applications, though, this concept proved not to be commercially practical. However, since Kapitsa's death, there have been proposals to perhaps place giant solar panels into Earth orbit to produce electrical energy. This energy could be beamed to Earth in the form of microwaves, with devices similar to planotrons at each end of the microwave link.

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See also: Albert Einstein; Heike Kamerlingh Onnes; Ernest Thomas Sinton Walton.

JOHN KAY

British machinist and engineer

Kay introduced two significant reforms into the technology of weaving, in advance of the Industrial Revolution, which facilitated the eventual mechanization of textile manufacture. The importance of his innovations became controversial when he was held up posthumously as a key example of the shabby way in which England allegedly treated its inventors.

Born: July 16, 1704; Walmersley, near Bury, Lancashire, England
Died: 1780 or 1781; southern France
Primary field: Manufacturing
Primary invention: Flying shuttle

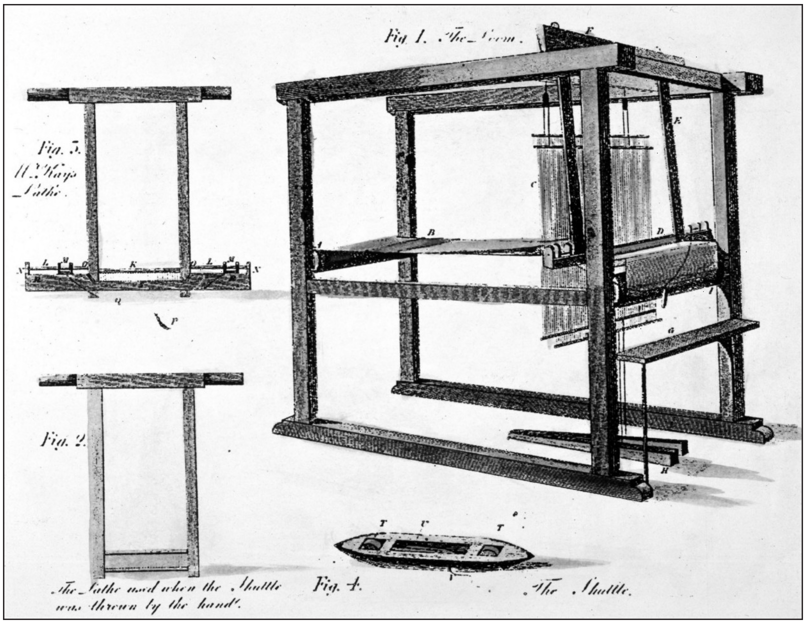
EARLY LIFE

John Kay was the fifth and last son of Robert Kay (1651-1704), the owner of Park Farm, and his wife Ellen, née Entwhistle. Robert Kay appears to have been a successful and relatively prosperous farmer, but his death three months before his youngest son's birth inevitably gave rise to difficulties for the family. John was educated locally but left school at fourteen to be apprenticed to a maker of reeds—devices used in weaving, whose function was to separate the threads of the warp and "beat up" the weft after each passage of the shuttle. He reportedly abandoned his master after a month, claiming that he had nothing left to learn. He appears to have been an extremely self-confident person with quarrelsome tendencies.

Anticipating a legacy of £30 from his father, which would come into his possession when he came of age (at twenty-one), Kay married Ann Holt on June 29, 1725. She bore six sons and six daughters before dying in childbirth in 1747. Kay apparently invented a new and improved reed in 1726, which substituted thin wire for the usual slivers of cane or reed, but did not patent it—an omission that he apparently became determined not to repeat. Three years later, he patented a new model of shuttle that was considerably lighter than existing ones, moved on four wheels, and featured a spring-operated "picker"—which is arguably the ancestor of all "mechanical hands." It was initially called a wheel shuttle, spring shuttle, or bobbin shuttle by virtue of its various accoutrements, but it eventually became known as a flying shuttle by virtue of the increased speeds it facilitated. It not only allowed weavers to work faster, enabling them to increase their daily production—or to reduce their working hours—but also made it easier to produce "broad goods" (wide sheets of cloth).

Life's Work

An improved model of the flying shuttle, launched in 1735, used a larger fitted spool and was widely introduced into the local woolen industry, enabling Kay to set up his own business as a shuttle manufacturer. He tried to charge his clients a "rent" (royalty) on every shuttle they employed, but the manufacturers refused to pay it, considering it extortion. He launched a series of lawsuits against some fifty-two manufacturers between 1737 and 1743, on the grounds of patent infringement, but ultimately failed to collect a penny in royalties and incurred heavy legal costs in the process.



An engraving from 1830 showing John Kay's flying shuttle loom (fig. 1), an unmodified lathe (fig. 2), a lathe modified by Kay (fig. 3), and Kay's shuttle (fig. 4). (The Granger Collection, New York)

Kay's propagandist descendant Thomas Sutcliffe (1791-1849), and others who tried to use Kay as an example of a genius cheated out of his due reward, echoed his own claim to have caused a "yarn famine" by increasing shuttle speeds, which was the direct cause of the development of automated spinning machines by John Wyatt, James Hargreaves, Richard Arkwright, and others, and hence of a key phase of the Industrial Revolution, but there is little hard evidence to support this boast. Opponents of that view suggest that the picking peg required a degree of skill that was quite difficult to master and that this limited the flying shuttle's use by contemporary weavers. Even so, it was a successful innovation, being adapted to numerous different kinds of cloth as the century progressed.

In 1738, Kay patented a wind-powered machine for raising water in mine shafts, but it was never widely employed. In 1745, however, he and Joseph Stell of Keighley obtained a patent for an improved, water-driven swivel loom—better known as a Dutch loom—for the weaving of "narrow goods" (tapes and ribbons). It was the first device to use tappets to control pedals. In the 1738 patent application, Kay described himself as an engineer, but by the time of the 1745 application he termed himself a "gentleman." In 1747, he left England for France. The reasons for the move are not entirely clear. His 1733 patent had expired and he was probably deep in debt, but his family were Jacobites and the failure of the 1745 rebellion was probably also a contributory factor. While he was in France, Kay learned of his wife's death, and that may well have put an end to any immediate plans he had to return to England.

Kay obtained a patent in France giving him a monopoly on the manufacture and sale of the flying shuttle, and in 1749 he was granted a government subsidy and a life pension, on condition that he severed all ties with his native land. He brought over three of his sons to help run his factory: James, John (1740-1791), and Robert (1728-1802)—who became an inventor in his own right, effecting significant improvements to the wheel shuttle. Kay soon found, however, that French weavers were counterfeiting his shuttle just as English manufacturers had. Between 1750 and 1754, he worked hard on improving the process of carding, eventually producing a much-improved carding machine that was widely adopted within the spinning industry, but he could not obtain a patent for it in England and does not seem to have made much money from it even in France. Nor could he bring himself to stay away from England, eventually visiting often enough to have his French pension revoked in 1759. In the meantime, the Kay-Stell Dutch loom was first put into operation in harness with a waterwheel at Keighley in 1750. The version that began operation at Garrett Hall, Manchester, in 1760 was that town's first true factory, anticipating the town's vast development into an important industrial city in the next century.

In 1764, Robert Kay applied to the Society of Arts for a reward for his father's inventions but was refused because of his defection to France; the society eventually consented to award him a bounty of £50 for his carding machine, but not until 1774, and it refused to give him anything for the flying shuttle. By then, however, Kay's French pension had been restored, and he threw himself into further work on behalf of the French government, designing apparatuses for canal excavation, dock cleansing, temperature regulation, and silk manufacture. Étienne Mignot de Montigny was moved in 1779 to declare him a genius, but the statement might have been as much a diplomatic sally aimed at the English as a compliment to Kay's intellect. Kay's actual movements in France remain something of a mystery, and nothing more was heard from him after a letter sent from Sens in Burgundy in 1779. A report that he was living "in credit and affluence" in 1780 might have been a further exercise in diplomacy. At any rate, the exact date, place, and circumstances of his death remain a mystery, although he was definitely deceased by the spring of 1781.

The firm of Robert Hall and Sons erected a statue of Kay in his native town of Bury in 1877, which still exists, although it was moved to Barnsley in 1974. A Kay Memorial was inaugurated in 1908 in Kay Gardens, Bury.

IMPACT

Kay's posthumous reputation owed much to the propagandizing efforts of his great-grandson Thomas Sutcliffe, who fought at Waterloo before being appointed governor of the Juan Fernández Islands. Sutcliffe followed up *An Exposition of Facts Relating to the Rise and Progress of the Woollen, Linen, and Cotton Manufactures of Great Britain* (1843) with a more specific *A Testimonial in Behalf of Merit Neglected and Genius Unrewarded, and Record of the Services and Sufferings of One of England's Greatest Benefactors* (1847), issued as part of a campaign to obtain state relief for Kay's poorer descendants.

This appeal made Kay a legendary character in the late nineteenth century; Sutcliffe popularized an oft-quoted but highly dubious anecdote relating how Kay was driven to seek refuge in France in 1753 (six years after his actual emigration) when his home was attacked by Luddite machine-breakers intent on his murder. The suggestion was put about that the target of the attack was a new spinning machine invented by Kay in association with one Thomas Hayes, or Highs, who had unwisely bragged about it to Richard Arkwright, who had then made a fortune out of it. The rumor was given extra credence by the fact that Arkwright had commissioned a man named John Kay to build a model of his machine—but that was a clockmaker from Warrington, not John Kay of Bury.

Kay's historical importance was undoubtedly inflated by this legend-mongering, but the flying shuttle was a significant innovation and a key step in the gradual development of a fully automatic loom. His carding machine was also a notable step forward in textile production. Even if Kay's accomplishments were slightly overstated, the fact that he became an exemplary legend is significant in itself, as an admonitory reminder that English technological expertise often did go unremarked and unrewarded for far too long. His own tragedy was compounded by the fact that the nineteenth century campaign mounted on his behalf accomplished little or nothing to ensure that future English engineers would be afforded the status that their contribution to national wealth ought to have entitled them.

—Brian Stableford

THE FLYING SHUTTLE

A weaving loom works by raising up two sets of threads alternately by means of two horizontal bars (known as "heddles") equipped with eyelets, through which the thread is passed. The raising of each individual set of warp threads leaves a space (the "shed") through which a shuttle is passed. The shuttle used prior to John Kay's invention had to be passed from hand to hand, limiting the breadth of the cloth to the length of the weaver's arm. The flying shuttle was mounted on wheels and moved between two shuttle boxes mounted to either side of the loom along a wooden track, or "shuttle race," in response to a jerking action from the weaver, which activated the "picking peg."

The flying shuttle was considerably faster than a hand shuttle and facilitated the weaving of wider bolts of cloth. There is no doubt at all that the flying shuttle was an important technical advance and a crucial first step in the automation of weaving, but historians dispute the speed with which it was actually taken up by manufacturers and the extent of the manufacturers' guilt in refusing to pay royalties for its use. Kay's detractors suggest that his particular model was too awkward to use without considerable modification and that the flying shuttles that achieved dramatic improvements in production owed as much to other improvisers as to him. The basic design-concept was, however, a stroke of brilliance if not of genius, and was certainly a key contribution to the eventual mechanization of the textile industry.

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See also: Sir Richard Arkwright; Edmund Cartwright; James Hargreaves.

JOHN HARVEY KELLOGG

American physician and surgeon

A health reformer, Kellogg advocated a way of life that included exercise, cleanliness, and a vegetarian diet focused on fruits, nuts, and whole grains. His search for a ready-to-eat form of whole grains led to the invention of flaked breakfast cereal.

Born: February 26, 1852; Tyrone, Michigan
Died: December 14, 1943; Battle Creek, Michigan
Primary field: Food processing
Primary invention: Cereal flakes

EARLY LIFE

John Harvey Kellogg was born to John Preston and Ann Stanley Kellogg on their farm near Tyrone, Michigan, in 1852. A few months after his birth, Kellogg's parents embraced the faith of Seventh-day Adventists. When Kellogg was four years old, the family moved to Battle Creek, Michigan. Though he received irregular schooling as a boy, John became an avid reader. He worked in his father's broom shop for a year, until at the age of twelve he first attended school full time. After a year in school, he became acquainted with James and Ellen White, who helped found the Adventist Church. When James White, president of the Review and Herald Press, heard about the boy's impressive performance in school, he offered him a job in 1864. As he worked his way up to typesetter and proofreader, Kellogg became familiar with Ellen White's writings on Seventh-day Adventist health principles, which included vegetarianism.

At the age of sixteen, Kellogg accepted a position in a rural school, but he found the job too taxing on his somewhat delicate health. Eventually, he finished high school. As they hoped to improve the medical foundations of the Seventh-day Adventist's Western Health Reform Institute, the Whites offered Kellogg encouragement and financial support to acquire a medical education. Kellogg completed the six-month course in water therapy at Dr. Russell Trall's Hygieo-Therapeutic College in New Jersey and then attended the University of Michigan Medical School. He completed the first series of lectures but left because of the lack of clinical instruction. James White then lent him money to complete his medical degree at Bellevue Hospital Medical School, which combined classroom and clinical teaching. Kellogg graduated in 1875. In 1878, he married Ella Eaton. They had no biological children, and it is likely that their marriage was never consummated. During their marriage, however, they reared forty-two foster children, seven of whom they adopted.

Life's Work

Kellogg led an extremely busy life filled with diverse projects. He joined his knowledge of standard medical practice in the performance of surgery with Adventist-inspired health principles that included vegetarianism, sexual continence, exercise, and hydrotherapy. In 1876, the Whites persuaded him to become chief physician of the financially failing Western Health Reform Institute. Within a year, Kellogg had renamed it the Battle Creek Sanitarium and had begun promoting its program of "biogenic" living to remain healthy. From its beginning, the sanitarium had a bakery to produce foods for those with digestive difficulties. As he initiated expansion and modernization of the facility during the 1880's, his control grew and he integrated his health principles and current therapies observed during travels to European medical centers and health spas. In 1892, he reorganized the sanitarium and acquired full control of it.

All of the activities had one goal: the improvement of human health by means of correct living. Kellogg proscribed the consumption of not only meat but also sugar and condiments—foods that Kellogg felt impeded proper digestion and led to sexual excess—as well as stimulants, such as coffee, tea, and chocolate. Tobacco and alcohol were also forbidden. On the positive side, he recommended legumes and nuts for protein, whole grains, and fresh fruits.

John Harvey Kellogg, pictured here in 1942 at the age of ninety. (AP/Wide World Photos)

Kellogg invented a number of grain foods, but not the first cereal. In 1863, James Caleb Jackson, whose ideas had inspired Ellen White, produced granula, a cereal composed of hard wheat-bran nuggets that required overnight soaking to eat. Kellogg conceived of the possibility of the "ready-to-eat" breakfast food during his days at Bellevue. In 1877, he invented a product called granola prepared from a mixture of oatmeal, cornmeal, and wheat baked into a thick biscuit that was then ground up. He had discovered that baking grain at a high temperature turned its starch into dextrin—that is, it completed the first stage of digestion and thus benefited those with digestive disorders. Kellogg started a mail-order business when former patients wanted to purchase his grain products. In 1890, he founded the Sanitarium Food Company. Besides granola, the company produced other healthful foods, such as crackers and a cereal-based coffee substitute. In 1894, Kellogg invented his most famous food, the flaked breakfast cereal, with the help of his brother, Will Keith Kellogg. When the Adventist board of directors refused to finance Kellogg's ongoing research, Kellogg continued at his own expense and with his brother set up the Sanitas Food Company to market the new cereal as Granose.

In 1892, Kellogg invented a peanut butter composed of boiled peanuts mashed into a paste. He developed other vegetarian foods such as Savita Gravy (a bullion made from brewer's yeast), meat substitutes composed of boiled peanut mash combined with wheat gluten or starch and flavored like different meats or salmon, and Bromose, a milk substitute composed of cereals and nuts that he touted in his 1896 book *The Stomach* for its digestibility and efficacy for weight gain. One meat substitute, Nuttose, introduced in 1896, served as the main dish for sanitarium dinners.

In 1902, the Battle Creek Sanitarium burned down, and during the process of rebuilding, the Adventist Church quarreled with Kellogg, both over his use of profits for his projects instead of for the church's programs and over the suspicion that he ascribed to pantheism and not to the church's theology. Though the church severed its relationship with Kellogg in 1907, he nevertheless retained control of the sanitarium and its food companies.

Relations between the Kellogg brothers soured over different business and marketing strategies; after almost a decade of conflict, the courts gave Will exclusive rights to sell corn flakes and to use the Kellogg name. John Kellogg continued to promote his ideas on food and diet. He accepted autointoxication, a theory that viewed the fecal content of the colon as the source of illness. Inspired by the views of microbiologist Ilya Mechnikov that attributed the long lives of Bulgarians to the consumption of beneficial bacteria in yogurt, Kellogg became an advocate of yogurt therapy by the end of the first decade of the twentieth century. At the sanitarium, patients ate yogurt and received yogurt enemas to maintain a healthy colon.

By the end of the second decade, Kellogg had discovered a nutritious meat substitute in the soybean, devoting several pages to soy-based foods in his *The New Dietetics* (1921). He invented foods such as an acidophilus soy milk in 1933, patented the following year, and a soy cheese and sold them through his Battle Creek Food Company. During his life, he received a total of thirty patents for food products, exercise equipment, and even an electric blanket. He also wrote more than fifty books.

At its zenith between 1915 and 1930, the sanitarium attracted many notable visitors such as Edgar Welch of grape juice fame, John D. Rockefeller, Jr., and J. C. Penney. In the early 1930's, the sanitarium experienced severe financial difficulties and was placed in receivership in 1933. After years of negotiations and reorganization, the U.S. government bought several of the main buildings in 1942. Kellogg had hoped to restore the sanitarium, but the ensuing legal and personal troubles adversely affected his health. He died on December 14, 1943, at the age of ninety-one.

Cereal Flakes

During the 1880's and early 1890's, patients at John Harvey Kellogg's Battle Creek Sanitarium (formerly the Western Health Reform Institute), a health retreat operated by the Seventh-day Adventists, began their day by eating dry granola. When an elderly woman complained that her dentures cracked upon eating the hard cereal, Kellogg began a search for ways to make dextrinized cereals that were more soluble. One product already available, shredded wheat, invented in 1893 by Henry D. Perky, did not appeal to his clients. In 1894, Kellogg discovered the process to produce the cereal flake quite by accident. Initially, he attempted to roll out kernels of raw wheat soaked in water, but he obtained only a separation of the starch from the bran. Then he cooked the wheat and forced it between rollers but obtained only a sticky paste. One day after boiling a quantity of wheat, Kellogg was called away before he tried to roll it. When he returned much later, the wheat dough had dried, but he decided to have it rolled out. He obtained flakes that produced a palatable, easily chewed cereal when toasted. With further experimentation, Kellogg and his brother discovered that the cooked wheat had to cool down before being rolled. Further trials determined how fast to pass the dough through the rollers, as well as how best to scrape off the flakes. Kellogg filed a patent on May 31, 1895, for the flaked wheat and its production process. The patent also applied to barley, oats, corn, and other grain flakes.

Kellogg handed over to his brother the management of the Sanitas Food Company that marketed the flaked cereal. During its first year of operation, the company manufactured fifty tons of the flaked wheat cereal that it called Granose. Other manufacturers found ways to infringe on Kellogg's patent, with the result of severe competition. The most famous flake, the corn flake, was not the invention of John Harvey Kellogg but his brother, Will Keith Kellogg. In 1898, Will developed the corn flake and made it more palatable by adding sugar, against his brother's food philosophy. Will introduced corn flakes commercially in 1905 and in the following year acquired exclusive rights to it from his brother. In 1906, he founded the Battle Creek Toasted Corn Flake Company, renamed the Kellogg Toasted Corn Flake Company in 1909, and reincorporated simply as the Kellogg Company in 1922, after it had expanded its product line.

Impact

The development of ready-to-eat cereals revolutionized the breakfast habits of Americans. Before their introduction, a typical American breakfast consisted of ham and fried potatoes. Kellogg's flaked wheat cereal enjoyed sales of more than fifty tons at twelve cents a pound during its first year. A sixty-cent quantity of grain could thus be turned into $12 in sales. This success and the potential for profit inspired a number of competitors, including C. W. Post, who had been a patient at the Battle Creek Sanitarium. Post introduced Grape Nuts in 1897 and in 1908 introduced Elijah's Manna, a corn flake cereal, later sold as Post Toasties. By the first decade of the twentieth century, more that forty companies selling cereals existed in the area around Battle Creek. Almost immediately, the competitors found ways to circumvent the patent taken out by Kellogg by adding ingredients to the flakes, for example. The courts ruled the patent invalid in 1903.

While Kellogg's views on autointoxication soon met with disavowal from the medical profession, some of his products, such as the meat substitutes, did find markets in European countries, notably Germany. Eventually, foods such as soy and yogurt reached the standard market in the United States. Another food introduced by Kellogg, the psyllium seed, is the ingredient in contemporary laxative foods. Ironically, cereal is not highly nutritious unless fortified.

—Kristen L. Zacharias

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See also: George Washington Carver; Henri Nestlé.

LORD KELVIN

Irish physicist and engineer

Lord Kelvin was the great pioneer of thermodynamics and the architect of the Atlantic cable, but his most significant contribution to the evolution of science was his amazingly prolific development of new measuring devices and his insistence on the crucial significance of accurate and assiduous measurement as the key to success in pure and applied science.

Born: June 26, 1824; Belfast, Ireland (now in Northern Ireland)
Died: December 17, 1907; Netherhall, Ayrshire, Scotland
Also known as: William Thomson (birth name); Baron Kelvin
Primary field: Physics
Primary inventions: Absolute temperature scale; Atlantic cable

EARLY LIFE

William Thomson was the second son, among seven children, of James Thomson (1786-1849) and his wife, Margaret, née Gardner (c. 1790-1830). Both his parents were Scottish, but at the time of his birth his father was professor of mathematics at the Royal Belfast Academical Institution in Ireland. In 1832, however, James took the chair of mathematics at what was then Glasgow College (subsequently renamed the University of Glasgow). Thinking that he could educate his children better than any school, James Thomson educated them at home but allowed William and his older brother James to matriculate at the college in 1834, when William was still only ten years old. The two brothers worked very closely together thereafter, although William was broadly interested in natural philosophy, while James was more strictly an engineer.

Thomson became eligible for his Glasgow bachelor's degree in 1839 but did not take it because he wanted to study as an undergraduate at Cambridge University. He entered Peterhouse College on April 6, 1841, where his academic brilliance was soon recognized and rewarded, although he spent a great deal of time rowing and playing the cornet—with the result that he graduated only second in his class, losing the coveted title of "senior wrangler" to a more assiduous rival. Thomson was appointed as a fellow in June, 1845, and immediately took on editorial responsibility for the *Cambridge Mathematical Journal* (*CMJ*), in which he had already published eleven papers; these included the first of his pioneering papers on heat conduction, which drew a mathematical analogy between that process and electrostatic induction.

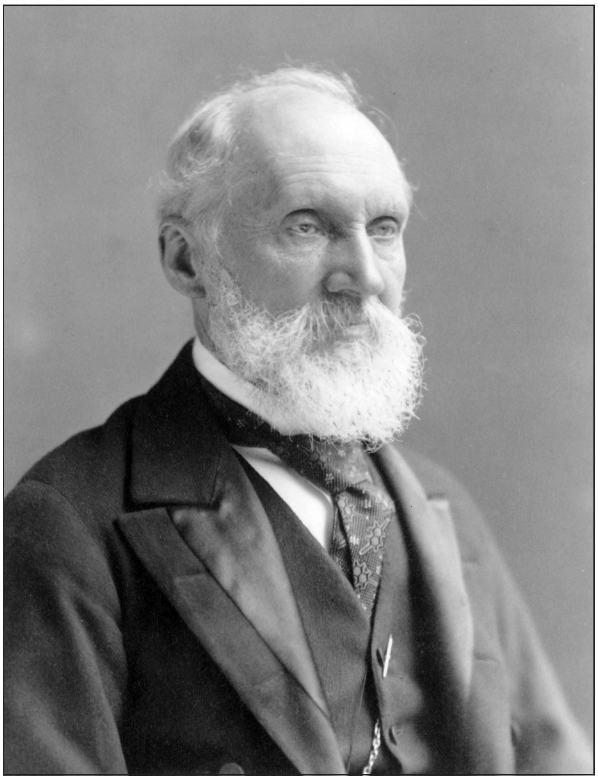
LIFE'S WORK

Thomson was, effectively, biding his time in Cambridge while waiting for an opportunity to open up at Glasgow. The death of Professor William Meikleham in May, 1846, vacated the chair of natural philosophy, to which Thomson was unanimously elected on September 11 of that year. Thomson continued to edit the *CMJ* for several more years, however, contributing a further thirty papers to the journal by 1850. He gave up his editorship in 1852 after failing to persuade the journal's owners to broaden the scope of the *CMJ* to take in applications of mathematics to the whole field of natural philosophy. He was initially delighted when the second wrangler of 1854, James Clerk Maxwell, took up his crusade, as well as carrying forward his work in electrostatics. In September, 1852, Thomson married his cousin Margaret Crum, the daughter of a prosperous cotton manufacturer who had a strong interest in industrial chemistry; unfortunately, her health broke down thereafter and she remained an invalid until her death in 1870.

As soon as he had succeeded Meikleham, Thomson, in alliance with other young professors, embarked on a crusade to reequip the university's laboratories, which succeeded so well that Glasgow became one of the leading research centers of the period. He did the same again, much later, when the university moved to a new site in Gilmorehill in 1870, supervising the building and equipment of a state-of-the-art physics laboratory. The necessity of having the best equipment, and constantly improving that equipment, was an obsessive conviction that provided the foundation for all Thomson's discoveries; in order to apply mathematical precision to physical problems, accurate measurement was a fundamental necessity, and it was his talent for refining measuring devices that facilitated his practical discoveries.

Thomson had long been aware of the existence of an extremely rare and esoteric treatise by Nicolas Léonard Sadi Carnot on heat conduction but only managed to lay his hands on a copy in 1849. By that time, Thomson's own research had made significant progress: He had developed the absolute scale of temperature named for him a year earlier, and he was immediately able to fuse his ideas with Sadi Carnot's to develop the initial formulation of the principle of the conservation of energy and the first and second laws of thermodynamics. The word "entropy" was not co-opted until much later, but it was Thomson who realized the importance of the concept and its application to the conversion of energy in various kinds of machines. It was he who popularized the term "energy" as a fundamental concept in physics.

Because he was interested in evolutionary theory—having read Robert Chambers's *Vestiges of the Natural History of Creation* (1844)—Thomson immediately attempted to apply his thermodynamic insights to the question of the age of the Earth in an article for the *Philosophical Magazine*. His argument estimated the time span during which the Sun had been radiating (and would continue to radiate) heat, based on the assumption—borrowed from Hermann von Helmholtz—that its heat must be derived from the energy of gravitational collapse. His conclusion, that the solar system must be millions of years old, helped pave the way for Charles Dar-



William Thomson, Lord Kelvin. (Library of Congress) win's evolutionary theory, which required some such time span but also suggested that the Earth's future was considerably more limited than its past—an idea that had a considerable influence on the imagery of subsequent futuristic fiction.

Thomson became a fellow of the Royal Society in 1851, and his prestige was such by then that he was asked in 1854 to tackle the thorny problems associated with the transmission of electricity and telegraphic signals in submarine cables. In order to put his mathematical analyses of the problem to the test, in the laboratory and the field, he needed to develop new measuring devices. His association with instrument maker James White, begun in 1845, became crucial to this research. In 1856, Thomson became a director of the Atlantic Telegraph Company, and he accompanied its first expedition in 1857. The eventual fruition of this endeavor won him a knighthood in 1866. He began taking out patents for the new instruments he devised, the first of them being granted in 1865; he had seventy to his credit by the time he died. All the signals transmitted by submarine cables between 1866 and 1883 employed his instruments, and the various electrometers he devised formed the basis of designs used in laboratories and workshops the world over. He also developed conventional depictions of electrical circuits ancestral to those still in use.

The wealth generated by his telegraphic patents allowed Thomson to buy a 126-ton yacht, the *Lalla Rookh*, in 1870, which became a floating laboratory and home-away-from-home. He undertook numerous cruises in the boat, experimenting with sounding devices and compass housings—coming up with improved designs in both instances, which were gladly adopted by the Admiralty. While docked in Madeira on one such expedition, he made the acquaintance of the Blandy family and married Frances Anna Blandy (c. 1838-1916) in June, 1874. In the meantime, his association with James White continued to develop; by 1880, they were joint owners of a major instrument factory, although the partnership was not formally incorporated until 1900.

Thomson began work on an ambitious *Treatise on Natural Philosophy* (1867; expanded 1879) in collaboration with his colleague Peter Guthrie Tait, but the projected later volumes were never completed because he was too busy with his practical endeavors. The core of Thomson's life's work was represented by the vast quantity of his scientific papers. A collection of those on electrostatics and magnetism was issued in 1872, and the remainder was assembled in a six-volume set between 1882 and 1911. In 1871, he became the president of the British Association, and he served several terms as president of the Royal Society of Edinburgh before becoming president of its London parent from 1890 to 1895. He had been awarded its prestigious Copley Medal in 1883. He was elevated to the peerage in 1892. He had begun building a large house at Netherhall in the 1870's, which became his country seat and permanent residence when he eased up on his globe-trotting, although he owned a town house in London as well.

Like many other men, Kelvin became increasingly set in his ideas as he grew older, and he became stubbornly hostile to the scientific theorists whose work threatened to render his obsolete, especially James Clerk Maxwell. Kelvin remained a stubborn positivist, deeply antipathetic to Maxwell's tendency to invent unobserved—and

THE ATLANTIC CABLE

William Thomson's investigations of the transmission of signals in submarine cables, initially carried out in the laboratory, revealed that the crucial technical problem blighting the technology arose from the variations in the quality of supposedly pure copper cables. In order to introduce better quality control, it was necessary to introduce more accurate measuring devices into the production and deployment of such cables; the key invention that facilitated the latter part of this prospectus was Thomson's marine mirror galvanometer, which accompanied him on his expeditions aboard cable-laying ships in 1858.

Thomson eventually took charge of the first attempt to lay an Atlantic cable by the HMS *Agamemnon*; that cable broke, but Thomson was able to prove that the fault lay in the materials, not his calculations. The first cable that Isambard Kingdom Brunel's *Great Eastern* attempted to lay in 1865 also broke, but another was successfully laid the following year and the former was subsequently repaired, launching a new era in transatlantic communication.

Thomson was not as closely involved in the second phase of the operation as he would have wished, because he had broken his leg in 1861 while curling at Largs, and this had restricted his movements. Once the cable was laid, however, he became intensely involved in the practicalities of its usage, in association with Fleeming Jackson and Cromwell Varley, and he was primarily responsible for the refinement of the equipment over the next fifteen years, making the endeavor one of the most triumphant examples of nineteenth century applied science.

sometimes unobservable—entities in response to the mathematical elegance of his theory of electricity. Kelvin also refused to relinquish the theory on which he had based his estimate of the Sun's age when younger men began to favor the hypothesis that the Sun's heart was actually generated by radioactivity. These late lapses could not detract, however, from the enormity of his earlier achievements.

IMPACT

During his lifetime, Kelvin made a tremendous impact on technological development by virtue of his contributions to instrumentation and telegraphy, and his formulation of the fundamental principles of thermodynamics guaranteed him an important niche in the history of scientific theory. As measuring instruments were further refined and telegraphy became much more sophisticated in the twentieth century, his particular contributions became less noticeable, relegated to the status of a phase in technological evolution, but they were nonetheless crucial—a fine testimony to his unrelenting inquisitiveness and practical genius.

Perhaps ironically, Kelvin's off-the-cuff attempt to calculate the likely life span of the Sun based on the mistaken assumption that its heat was generated by the energy of gravitational collapse continued to be widely quoted long after the discovery that the Sun's heat is actually generated by nuclear fusion. Although it was intended to deliver a killing blow to contemporary creationist accounts, the essay's estimate of the age of the solar system is nowadays frequently cited by creationists avid to challenge more modern and more reliable calculations, which estimate the age of the Earth in billions of years rather than millions. Such mischievous citations have, alas, deflected some attention away from the towering example Kelvin provided in his own day.

—Brian Stableford

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See also: Sir Humphry Davy; Oliver Heaviside; Hermann von Helmholtz; Heike Kamerlingh Onnes; Carl von Linde; Robert Stirling.

CHARLES F. KETTERING

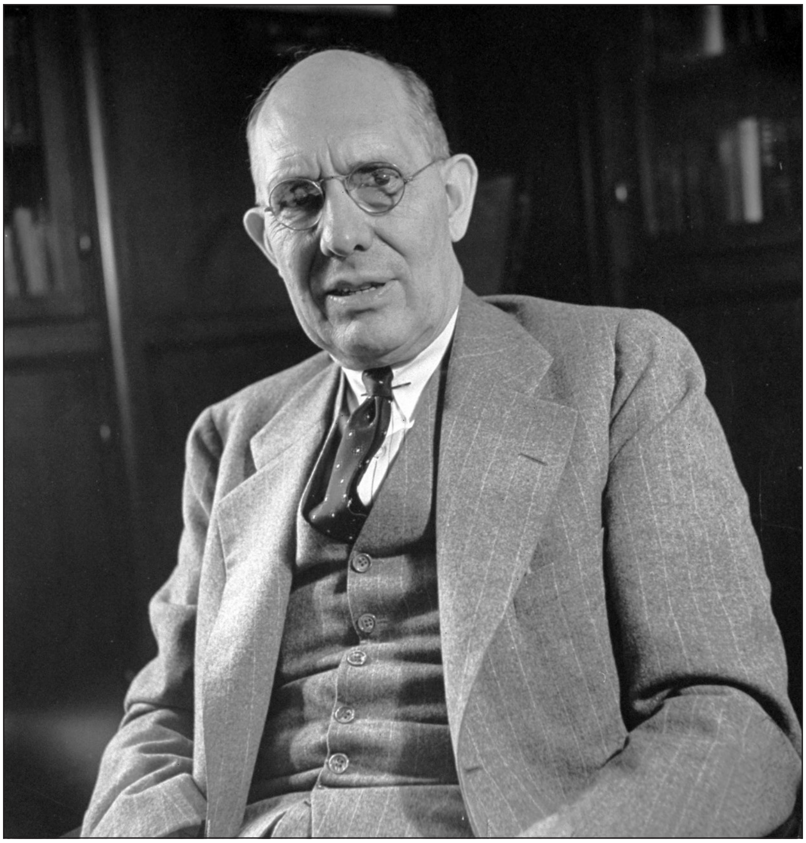
American electrical engineer

Kettering is sometimes referred to as the Thomas Alva Edison of the twentieth century. His numerous inventions contributed to a wide range of fields and included devices that improved railroad engines, automobiles, refrigerators, and airplanes.

Born: August 29, 1876; Loudonville, Ohio
Died: November 25, 1958; Dayton, Ohio
Also known as: Charles Franklin Kettering (full name)
Primary fields: Automotive technology; electronics and electrical engineering
Primary inventions: Freon refrigeration and air conditioning; electric starter; Kettering Aerial Torpedo

EARLY LIFE

Charles Franklin Kettering was born on August 29, 1876, in Loudonville, Ohio, where his parents, Jacob and Martha Kettering, owned a farm. As a child, he was educated in a one-room schoolhouse, then attended Loudonville High School on an academic scholarship. Determined to go to college, he taught school for three years to raise the



Charles F. Kettering. (Time & Life Pictures/Getty Images)

necessary funds. He entered Ohio State University in 1898 to study electrical engineering and worked for the Star Telephone Company digging holes for telephone poles.

While Kettering worked for Star, supervisors noted his ability to fix things and discover new ways of solving problems. He showed an aptitude for ascertaining and resolving difficulties that Star engineers could not. For example, when Star was unable to bring service to remote rural areas because of issues with overheating, Kettering resolved the problem by creating a relay system that extended the lines' reach to outlying areas.

A bout of scarlet fever as a child left Kettering very nearsighted. During college, he suffered severe headaches that forced him to leave school in order to save his eyesight. When he returned to Ohio State, his attendance was spotty, as there were months at a time when he was unable to read. Still, with the help of friends who read book assignments to him, he was finally able to graduate with a degree in electrical engineering in 1904 at the age of twenty-eight.

LIFE'S WORK

Edward Deeds, chief of research and development for the National Cash Register (NCR) Corporation in Dayton, Ohio, contacted Ohio State seeking an innovative engineer. The engineering department recommended Kettering for the job, and Deeds hired him to work for NCR's research department for $50 per week. Kettering moved to Dayton and on August 8, 1905, married Olive Williams. Their only child, Eugene, was born on April 20, 1908.

The first challenge Kettering tackled at NCR was the issue of obtaining credit approvals for customers in department stores. At the time, the process required a cashier to leave his or her post and go to a separate office to receive approval; this process took a long time and frustrated customers and cashiers alike. Using knowledge acquired from his work with the telephone company, Kettering developed a phone attachment for the cash register. Without leaving their stations, cashiers accessed the credit office through a phone line attached to the register and received quick credit approval for their customers. From their distant office, credit managers had only to push a button at their desk to stamp approval directly onto the customer's receipt at the checkout counter. Next, Kettering replaced spring-powered cash registers with electronic machines by creating a small engine to power the machine. The new electronic register made NCR the leader in its field for many years to come. Kettering also developed an accounting machine for banks that rid them of the need to write account cards for each customer. During Kettering's five years at NCR, he was awarded twenty-three patents.

During evenings and weekends, Kettering worked on improving the automobile, a new invention that was sweeping the nation and that piqued Kettering's curiosity. He tinkered with the idea of a new ignition system for automobiles. The ignition system in use at the time relied on dry-cell batteries that worked well at normal to high speeds but sputtered and frequently died at low speeds. The batteries were expensive and required replacement after only a few hundred miles. Deeds, also fascinated with the idea, loaned Kettering the use of his carriage barn to work on his idea. In 1909, Kettering resigned from NCR to work full-time on his new invention.

Kettering devised a stationary coil that provided a more continuous spark to the ignition. He installed the device on Deeds's car, and Deeds and his wife were able to drive from Dayton to New York City and back without stalling once. The new system also caused less wear and tear on the battery, which now lasted ten times longer. Kettering and Deeds sold the idea to Henry Leland, head of the Cadillac Motor Company, who ordered eight thousand of the new ignitions. With a big order but without a company to subcontract the manufacture of the ignitions, Deeds and Kettering formed the Dayton Engineering Laboratories Company (Delco) in 1909.

Kettering turned his attention to a new way to start the ignition. Early automobiles created the spark that started the ignition by the driver vigorously turning a crank on the front of the car. It took a strong back and a lot of muscle to do so, and sometimes drivers were injured in the process. Using the same principles he employed to electrify the cash register, Kettering developed a small engine that powered a self-starter that required only the turn of a key or push of a button, making the cumbersome crank obsolete. Cadillac Motors ordered twelve thousand electric starters. Unable to subcontract such a large order, Delco opened a factory near downtown Dayton to manufacture the new system. Soon, Delco's self-starting ignition became standard in all automobiles.

During Easter weekend in March, 1913, torrential rains and melting snows combined to threaten Dayton. On March 25, levees holding back the Mad and Miami rivers broke, causing floodwaters to storm into the city. Ninety-seven people and fourteen hundred horses died; $67 million in property was damaged. Fourteen thousand homes were destroyed and fifty thousand residents needed shelter. The Delco factory was under twenty-seven feet of water, and forty-seven men were stranded. Kettering made his way toward the floodwaters and helped establish electrical power to shelters and feed the newly homeless. He set up twenty-five prefab homes for Delco executives left homeless by the disaster and paid to rebuild and refurnish the homes of Delco employees that had been destroyed by floodwaters.

Kettering was also fascinated with the airplane. After learning how to pilot planes himself, he joined with Orville Wright and Edward Deeds to form the Dayton-Wright Company as a research facility in 1917. Plans for development were temporarily put on hold with the United States' entry into World War I in 1917. During the war, Kettering developed a new ignition system for the Liberty airplane, began work on a retractable landing

KETTERING'S REFRIGERATOR

Charles F. Kettering's inventions were not confined to the transportation industry. Along with Thomas Migley, Jr., the chemist at General Motors (GM) who assisted in the development of a quick-drying automotive paint and ethanol gasoline, Kettering developed an improved cooling system for refrigerators. Refrigerators of the time used dangerous gases such as ammonia, sulfur dioxide, and methyl chloride to generate the rapid evaporation needed to cool the unit. Several people, including more than one hundred people in a Cleveland hospital in 1929, were killed when chemicals leaked from their refrigerators and they breathed in the toxic fumes. Most home refrigerators were iceboxes that used large chunks of ice, delivered by an ice man. Kettering and Migley's version of a refrigerator replaced the cumbersome brine tank and toxic chemicals with a Freon-charged coil compressor. The new chemical compound ran through a compressor, which heated the Freon, then ran through a series of coils, turning it into a cool liquid that absorbed food heat and evaporated a cool vapor. In 1930, Migley demonstrated the safety of Freon by boiling it and breathing in the vapors before a gathering of chemists.

Production of Freon was taken over by DuPont. GM formed a new division to make household refrigerators, and Kettering was named the first vice president of the newly formed Frigidaire Division. The first automobiles with air conditioning were introduced in 1939 by Packard Motor Car Company. Freon was used as a propellant in aerosol cans for items ranging from hairspray and deodorant to insecticides. The manufacture of Freon was banned in 1996 because of concerns over the effects of the chlorofluorocarbon (CFC) on the environment, as CFCs contribute to the breakdown of the Earth's ozone layer.

Kettering expanded on his refrigeration ideas by designing a central air-conditioning system for the home he was building in Dayton, Ohio, Ridgeleigh Terrace. With the addition of ductwork and a fan system, his twenty-room residence became the first home in the United States to be air conditioned. His air-conditioning design was later used for homes, theaters, office buildings, and factories. It is believed that the addition of air conditioning to warehouses and factories contributed to a significant increase in productivity due to the improved comfort level of the workers.

gear, and designed an unmanned aerial vehicle (UAV). The body of his Kettering Aerial Torpedo, also known as the “Kettering Bug,” was constructed of wood and papier-mâché. It carried three hundred pounds of explosives fifty miles to a target, then dropped its load on the enemy. The Defense Department ordered forty thousand of the UAVs, but the Armistice was signed before they could be put to use extensively.

Kettering sold his interest in Delco to General Motors (GM) in 1916 for 100,000 shares of stock and became the head of the newly formed General Motors Research Corporation. During his twenty-seven-year tenure at GM, Kettering’s research department developed a diesel engine for railroad engines that, within a few years, completely replaced the steam engine. The department developed safety glass to reduce injuries during accidents, oversaw the development of leaded gasoline to reduce engine knocking in automobiles, and created quick-drying automotive paint. Kettering’s parents, who still lived on their farm in Loudonville, Ohio, were still without electricity, so Kettering devised a generator system using batteries that brought electricity not only to his parents’ farmhouse but also to homes and farms in rural areas throughout the country.

Kettering became a very wealthy man, and his philanthropic spirit had long-term effects. The Virginia Kettering Foundation, the Kettering Family Foundation, and the Kettering Medical Center teaching hospital and foundation continue to offer research, medical, and educational funding. During the 1940’s, Kettering’s older sister, Emma, died of cancer. In 1945, Kettering joined with Alfred P. Sloan, another GM executive, to form the Sloan-Kettering Cancer Research Institute to investigate causes and cures for the disease. The following year, Kettering’s wife, Olive, died of pancreatic cancer. Research, treatment, and education continue today at the research institute. Sloan-Kettering remains one of the top in its field in the areas of research, diagnosis, treatment, and prevention of cancer. Its hospital facility treats tens of thousands of patients annually and disseminates information to thousands online and through publications. Its educational facility provides training for doctors in cancer treatment and research.

Kettering also served as a trustee of and was a major contributor to Antioch University in Yellow Springs, Ohio. In addition to loans and grants to the university, he contributed money for a library and a science building. On June 24, 1955, Van Buren Township incorporated and became the city of Kettering, Ohio, named for its most famous citizen.

Kettering retired from General Motors in 1947 at age seventy-one. While there, he gained the nickname the “Wizard of General Motors” and acquired 140 patents. In retirement, he traveled throughout the country, often flying himself to the destination, to give thousands of speeches. He continued research at his home in Dayton, transforming his basement bowling alley into a research laboratory where he was particularly interested in discovering the way plants transformed sunlight into food energy. Kettering died from a stroke on November 25, 1958. He was survived by his son, Eugene, and wife, Virginia, who continued to oversee his philanthropic organizations.

IMPACT

Kettering’s wide array of inventions added convenience to the American lifestyle: Cars were easier to start and run, and engines knocked less frequently; homes and buildings were made more comfortable with air conditioning, and kitchens had more efficient, roomier refrigerators; rural homes were electrified and provided with telephone service.

Kettering believed that his research in photosynthesis would someday lead to an inexpensive and efficient fuel system for automobiles. By studying how plants transform sunlight into food, Kettering hoped to create automobiles that ran on sunlight. The ideas Kettering first used for the creation of the Kettering Aerial Torpedo led to the development of numerous unmanned air vehicles used for military surveillance and bombing operations.

Some of the implications of Kettering’s inventions were unanticipated. When automobiles first hit the road, there were few female drivers. The strong arm and back necessary to start a car frequently required a man’s assistance. One of the impacts of Kettering’s improvement to ignition systems was an increase in the number of female drivers. Author Rosamond Young theorized that soon after the electric starter became standard in automobiles, women’s skirts became shorter and petticoats began to disappear. Long skirts got in the way of automobile brakes and accelerator pedals. Thus, it is possible that Kettering’s invention even had an effect on women’s fashions.

—*Leslie A. Stricker*

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See also: Thomas Alva Edison; Frederick McKinley Jones; Carl von Linde; Nikolaus August Otto.

AL-KHWĀRIZMĪ

Persian mathematician and astronomer

Al-Khwārizmī was one of a number of scholars from various areas of the ninth century ʿAbbāsid caliphate who, through sponsorship from the caliphs, gathered and developed scientific knowledge pioneered by earlier Indian, Greek, and Roman civilizations. Much of their work, including al-Khwārizmī’s famous mathematical treatises, passed on to Europe through medieval translations from Arabic to Latin.

Born: c. 780; probably Khuārizm (now in Khiva, Uzbekistan)
Died: c. 850; possibly Baghdad (now in Iraq)
Also known as: Muḥammad ibn Mūsā al-Khwārizmī (full name)
Primary fields: Astronomy; mathematics
Primary invention: Algebra

EARLY LIFE

It is difficult, if not impossible, to reconstruct personal details concerning the early life of al-Khwārizmī (ahl-KWAHR-ihz-mee). A Persian by ethnic origin, al-Khwārizmī was born about 780, probably in Khwārizm (the modern-day region of Khiva, located south of the Aral Sea in Uzbekistan). There is some disagreement about his actual place of birth, in part because Khwārizm in that period was a subregion of the ʿAbbāsid caliphate’s vast eastern province of Khorāsān, the borders of which were not clearly defined. He died near the age of seventy possibly in Baghdad, capital of the ʿAbbāsid caliphate. Because so little is known about al-Khwārizmī’s life prior to his long stay in Baghdad, it is reasonable to assume that—like so many notable figures whose careers were eventually made in the ʿAbbāsid capital—he probably moved in stages from the quite undeveloped eastern regions of Islam, possibly staying for periods in politically and culturally advanced centers that had developed in Khorāsān, especially in the era of the Samanids, whose ascendancy after 819 in Balkh (now in northern Afghanistan) extended westward into ʿAbbāsid Iran. The fact that most of al-Khwārizmī’s scholarly life was passed in Baghdad may have tempted some, including the well-known annalist al-Ṭabarī (c. 839-923), to assume that he was actually born in a region close to the capital.

LIFE’S WORK

It was during the caliphate of al-Maʾmūn (r. 813-833) that a very important step was taken to establish Baghdad as a center of learning that would attract scholars from distant places. Building on precedents begun by his famous father, Caliph Hārūn al-Rashīd (r. 786-809), al-Maʾmūn founded an institution known as the Bayt al Hikma (house of wisdom). His goal was to bring to Baghdad Muslim scholars who could advance various fields of knowledge by delving into translations of major Greek and Sanskrit works. It is generally agreed that the Arabic translations of Greek texts that were subsequently lost in the original eventually provided a channel for “recovery” (via translation from Arabic into Latin) of major works in Hellenic philosophy and science. Indeed, several works in Arabic of al-Khwārizmī himself would eventually be saved from oblivion thanks to medieval European scholars translating the Arabic works into Latin. As part of his patronage to knowledge and science, al-Maʾmūn also built several observatories to facilitate astronomical studies, a field which al-Khwārizmī pursued with great interest.

Before turning to al-Khwārizmī’s experiences at the Baghdad court and the scientific contributions he made during his career there, it is important to note that—because the Bayt al Hikma possessed a substantial library of manuscripts brought from India—there are a number of links between the work of al-Khwārizmī himself and Indian science and mathematical accomplishments. An outstanding example of this is frequently cited, even though somewhat misleading terminology is used in the general literature. A treatise he wrote when he was about fifty years old explored the attraction of using Hindu numerals, including the invaluable device of the zero, in making mathematical (indeed, even simple arithmetic) calculations. The use of these "Arabic" numerals—which, thanks to the adoption throughout the Arabic-speaking world of al-Khwārizmī's version of what the Hindus had developed originally, spread to Europe by around the twelfth century—greatly simplified methods of calculation by comparison to the unwieldy methods associated with Roman numerals.

Few scholars doubt that it was *Kitāb al-jabr wa al-muqābalah* (c. 820; literally, "the book of integration and equation") that established al-Khwārizmī in the annals of science and mathematics. Indeed, the word "algebra" is derived from the term *al-jabr*, even though that particular branch of mathematics formed only part of al-Khwārizmī's concerns in this very extensive work. The book does, however, stand as a major systematic treatment of what became the subfield of algebra. By the time the book was translated into Latin in the twelfth century, most earlier works exploring what would become the main principles of algebra (ranging from Chinese and Indian studies dating from the first century B.C.E. through the key third century C.E. book *Arithmetica* by Diophantus of Alexandria) had been lost, making al-Khwārizmī's work an absolutely essential source. His intention in this work was more practical than theoretical. He frequently underlined the need for mathematical methods that could facilitate practical projects, such as canal digging and land surveys, and basic social interactions, such as calculation of inheritances and contractual dealings.

Algebra

Closer examination of the historical record shows that—although the word "algebra" derives from the Arabic word for "balancing" (*al-jabr*) in the title of al-Khwārizmī's major work, *Kitāb al-jabr wa al-muqābalah* (c. 820)—the ninth century Baghdadi scholar did not himself "invent" this important branch of mathematics. Nevertheless, Europeans who drew from Latin translations of his Arabic works could not have made advances in mathematics in the medieval era without his work. It is important to note that a number of issues associated with algebra that were of major concern to al-Khwārizmī drew the attention of other Muslim mathematicians—Persian scholars in particular—in the centuries immediately following his work and well before the "jump" was made linking ninth century Baghdad to the twelfth century Latin translation of *Kitāb al-jabr wa al-muqābalah* by Robert of Chester. This means that the principles of algebra were being refined and expanded within the Islamic world and India (probably drawing on al-Khwārizmī's book) in a more or less continuous way at least into the period of the Seljuk (Turkish) sultanate, which took over Baghdad in the mid-eleventh century. It was the Persian al-Māhānī (820-880), for example, who, confronting problems involving spheres and cylinders contained in the work of Archimedes, pioneered efforts to apply algebraic formulas to solve problems in geometry.

That the promising bases of al-Khwārizmī's work on algebra spread rapidly eastward within the broad cultural borders of the Islamic world (and possibly even farther) before they were "recovered" by Europeans is suggested by the significant number of ninth and tenth century Indian manuscripts citing and expanding on his mathematical theories.

Al-Khwārizmī's discussions of the various uses of what would later be called linear and quadratic equations, on the other hand, pioneered what became essentials for modern mathematics. Stated in layman's language applying to modern algebra, each term in a linear equation is either a constant or the product of a constant multiplied by the first power of a variable. Also in modern algebraic language, quadratic equations, which are used widely in solving geometric problems, are referred to as polynomial equations of the second degree.

Partly as a result of the wealth of information contained in Al-Khwārizmī's magnum opus, later students of the Latin translations associated his name with other major landmarks in mathematics. The term "logarithm," or "algorithm," for example, is a corrupted version of his name, as are the Spanish and Portuguese words for "digit," *guarismo* and *algarismo*, respectively.

Al-Khwārizmī's contributions to the field of astronomy—gathered under the title *Sindhind zij*—seem, as the title suggests, to have been the result of his exposure to Indian texts that reached Baghdad some time in the eighth century, together with basics contained in the astronomical tables of Ptolemy (c. 100-c. 178). Although the original versions of this work were lost, a Latin translation by Adelard of Bath of an Arabic tenth century synopsis of the original (plus other more extensive Latin versions) saved his findings for posterity. The main foci of al-Khwārizmī's work took the form of calendars. These were supplemented by calculations establishing the relative positions of the Sun, Moon, and known planets—opening the possibility of predicting eclipses of the Sun and the Moon. Many experts view the astronomical tables as a sort of composite work drawn from Hindu precedents and, to some degree perhaps, close examination of Ptolemy's second century work *Almagest*.

Al-Khwārizmī's scientific and mathematical involvement in astronomy may have tempted him to speculate on the usefulness of another field, astrology, as a guide to things less scientific. An example of this was a lesser work, essentially political in nature, which offered horoscopes of well-known individuals in the Baghdad court of his time.

Geography may be the area in which al-Khwārizmī's direct debt to Greek predecessors, and to Ptolemy in particular, is most obvious. The full title of his book *Kitāb ṣūrat al-arḍ* (book of the image of the Earth), tentatively dated near 833, actually gives direct credit to Ptolemy as its model. The work attempted to establish an accurate grid of longitudes and latitudes that, although at this early date could not encompass the (not yet known) entire spherical globe, did provide a system of calibration for locating some twenty-five hundred geographical sites. These included mountain regions, seas, and rivers, as well as well-known cities of the day. Al-Khwārizmī was also aware that his system could lay out and distinguish between "weather zones" falling at different latitudinal levels.

IMPACT

Al-Khwārizmī stands out as the most prominent representative of mathematical science as it was fostered in the court of the Arab ʿAbbāsid caliphs, especially under Caliph al-Maʾmūn. As his name suggests, al-Khwārizmī, like so many scientific and literary figures at the ʿAbbāsid court at that time, was not of specifically Arab origin. However, the Arabic texts he wrote, along with those of the philosopher al-Fārābī (who was also Persian by origin) and others active in Baghdad, filled a very important role. Without these Arabic texts, later European students of science and philosophy in the Middle Ages would have been deprived not only of such valuable original Islamic contributions to these fields of knowledge but also of such scholars' preservation of Greek sources that were subsequently lost.

—*Byron Cannon*

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See also: ʿAbbas ibn Firnas; Roger Bacon; Al-Jazarī; Ptolemy.

JACK ST. CLAIR KILBY

American electrical engineer

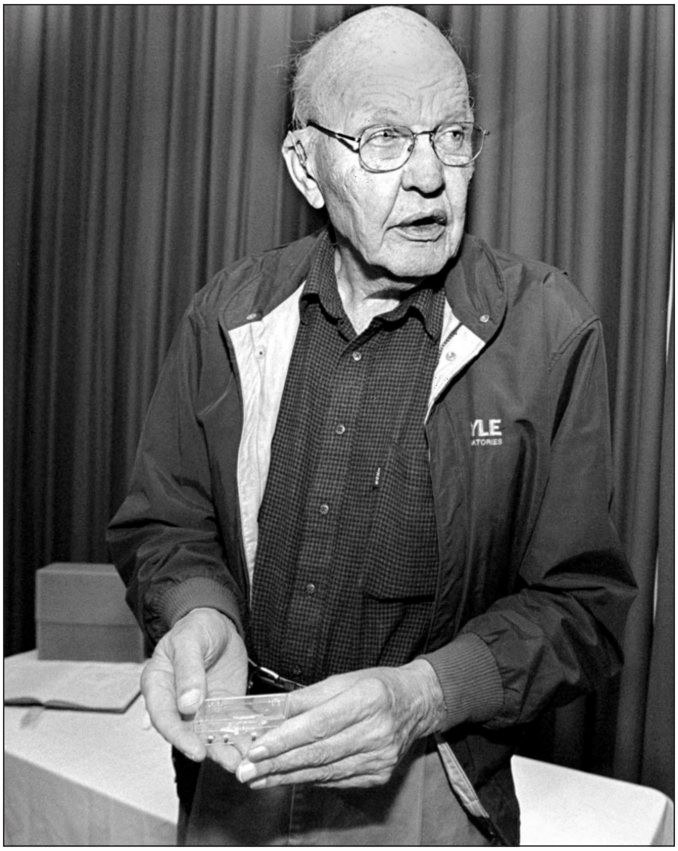
Inventor of the integrated circuit, for which he received the Nobel Prize in Physics in 2000, Kilby also invented many of its applications, such as the calculator, as well as unrelated inventions, such as the thermal printer.

Born: November 8, 1923; Jefferson City, Missouri
Died: June 20, 2005; Dallas, Texas
Primary field: Electronics and electrical engineering
Primary inventions: Integrated circuit (microchip); handheld calculator

EARLY LIFE

Jack St. Clair Kilby was born in Jefferson City, Missouri, in 1923. His father, an electrical engineer, moved to western Kansas a few years later, and young Jack often accompanied his father, who eventually became president of the Kansas Power Company, on inspection tours of power stations. Graduating from Great Bend High School in 1941, Kilby applied to Massachusetts Institute of Technology but missed the cutoff on the entrance exam by three points. Scrambling to apply to another school, he was accepted at the University of Illinois at Urbana-Champaign, but four months into his freshman year the United States entered World War II; a few years later, Kilby entered the U.S. Army Signal Corps, and later the Office of Strategic Services (the predecessor of the Central Intelligence Agency), stationed in India and China.

After the war, Kilby finished his bachelor of science degree in engineering at Illinois in 1947. He was hired by Centralab in Milwaukee, and while he worked there Kilby pursued a master's degree in electrical engineering from the University of Wisconsin-Milwaukee, which he received in 1950. At that time, Bell Labs was licensing electronics firms to produce the new transistor, and Kilby was chosen to attend the seminars in New York, a crash course in this cutting-edge technology. In 1958, Kilby joined the engineering team at an electronics firm in Dallas called Texas Instruments (TI). It was a TI tradition that all engineers take the same two weeks in summer for vacation, but because he had just been hired, Kilby was not yet eligible for vacation. Alone in the lab for two weeks, Kilby worked out the idea that would become the microchip.



Jack St. Clair Kilby holds his original design of the integrated circuit at Texas Instruments in Dallas, Texas, in 2000. That year, Kilby was awarded the Nobel Prize in Physics for his invention, which he built about forty years earlier. (AFP/Getty Images)

LIFE'S WORK

The problem that Kilby had set out to solve that summer alone in the lab was the single most vexing problem of the electronics industry in the middle of the twentieth century. The appearance of the transistor in 1948 had created unrealizable expectations of miniaturization on the part of the electronics consumer (particularly the military). The popular imagination expected Dick Tracy-type two-way wrist radios and computers that could fit on a desk. Neither was possible because of what engineers called the "interconnection problem," or the "tyranny of numbers." Even though the transistor was smaller, more durable, and cheaper than the vacuum tube it had replaced, it still had to be wired physically to other components in a circuit—which imposed a physical limit on miniaturization. Yet each digit of a digital calculation required a separate wire connection. With literally millions of connections in some complex equipment, hundreds are bound to fail.

Kilby's solution started with the fact that his new employers, Texas Instruments, had invested heavily in silicon, hoping to make transistors out of them. The basic components of electronics that had to be wired together were made of different materials—resistors of carbon, capacitors of metal and porcelain, transistors of germanium crystals. TI had already made transistors out of silicon by doping pure silicon with impurities such as arsenic. Silicon is a semiconductor, which means that on a scale of conductivity it is exactly halfway between conductors and nonconductors, or insulators. In its pure state, silicon will not conduct electricity, but the portion doped with the right impurities (called a "dopant") will become a conductor. One type of dopant will give the silicon a negative charge, another a positive. The doped portions would become the connections, eliminating the need for wires, and the pure silicon sections would be insulators. Kilby's idea did not stop there, however. He realized that resistors, capacitors, and transistors would not have to be manufactured separately and then wired together: A complete circuit could be manufactured together on one slice of silicon.

When the rest of the engineers returned from vacation, Kilby presented his idea to his boss, Willis Adcock. Adcock was interested, but did not think he could divert the company's resources from a U.S. Army contract they were working on, an alternative solution to the tyranny of numbers that Kilby felt (rightly) was doomed to fail. Kilby quietly pushed, and finally Adcock agreed to attempt the solution. If Kilby could produce a working resistor and a working capacitor out of silicon (they had already made workable transistors), TI would go ahead with the project of manufacturing them all in one piece—the solution that Kilby called the "monolithic idea."

Kilby produced working resistors and capacitors, but they still had wires. Even though his idea called for wireless and solderless printed or solid-state circuits, the prototype had wires, a fact that caused the U.S. Patent Office to award priority of patent on the microchip to Robert Norton Noyce, who had a similar idea at Fairchild Semiconductor a few months after Kilby. The patent battle had very little effect on the development of the chip, however, or on the profession's acknowledgment of Kilby's role in it. Both Kilby and Noyce became known as coinventors of the microchip, and neither resented the other's role.

In 1965, the chief executive officer of TI, Patrick Haggerty, who had introduced the transistor radio a decade earlier, gave Jack Kilby the task of doing for the adding machine what the transistor had done for the radio—bring it down to pocket size. Kilby assembled a team to work simultaneously on the four components of digital computing—input, memory, processor, and output. Kilby himself worked on the power source and the output. The final product, a two-and-a-half-pound calcu-

THE MICROCHIP

Jack St. Clair Kilby's solution to the miniaturization problem that faced the electronics industry in the late 1950's was both elegant and far-reaching. Kilby's role in the development of the integrated circuit, or microchip, is usually presented as conceptual, but he also worked on the prototypes of actual chips at Texas Instruments (TI) in the late 1950's and early 1960's. His starting point was TI's method of making transistors. Early transistors were of the point-contact type: negatively charged and positively charged portions were connected by tiny wires. The silicon transistors developed at TI before Kilby arrived there were of another type, known as "grown-junction," in which the positive and negative areas were made as the silicon crystal was being grown by introducing one type of dopant that would give the silicon a negative (N) charge, then another that would make the silicon positive (P), then another that would produce a negative charge. This NPN "sandwich" would create an electron flow through the crystal—a small, and relatively inexpensive transistor.

Kilby had studied British radar engineer Geoffrey Dummer's unsuccessful attempt just a few years earlier (1956) to create whole circuits out of a single block of material. Kilby's "monolithic idea" was a realization of the same idea, and he was able to do it in the laboratory. The resistance of the pure silicon itself would act as a resistor; the difference in potential at the PN juncture of the doped silicon was essentially a capacitor; the silicon transistor already existed. Kilby first had to prove that working silicon capacitors and resistors could be made. He cut resistors out of pure silicon and ground them to specifications with a dentist's drill. He made and tested capacitors. In September of 1958, he and his team succeeded in producing all three elements—capacitor, resistor, and transistor—in one block. He had produced the first microchip, leading the way to the era of the personal computer.

lator with light-emitting diodes (LEDs) for output, and retailing at $150, appeared by the end of 1966, and sold tremendously.

In 1969, Jack Kilby was awarded the National Medal of Science by President Richard M. Nixon. In 1978, Texas A&M University recognized his stature in the field by naming him Distinguished Professor of Electrical Engineering. He taught at the university until 1985. Kilby was inducted into the National Inventors Hall of Fame in 1982, and he received the National Medal of Technology in 1990. In 2000, forty-two years after he first thought of the microchip, Jack Kilby received the Nobel Prize in Physics—despite the fact that the only physics courses he ever took were in an engineering curriculum.

IMPACT

There are very few elements of twenty-first century life that are not directly affected by Kilby's inventions—particularly the microchip. Watches (even some analog watches), cell phones, computers—and of course, that other Kilby invention, the electronic calculator—all today bear Kilby's "monolithic" circuits of silicon. Some of the lesser-known spin-offs from the chip are detailed by Kilby himself in his 2000 Nobel Prize lecture. The Internet, of course, is one spin-off he was quick to acknowledge (though he was notoriously slow for an engineer to begin using it), but less obviously, he reminds people that cars are safer and emit fewer pollutants because of devices his invention made possible. Kilby's knack for the less obvious solution might well be another important part of his legacy to engineering. His favorite adjective for his solution to the tyranny of numbers problem was "unobvious." As a sort of elder statesman at Texas Instruments from the late 1960's until his retirement in 1983, Kilby became part of the TI story: His picture and biography will doubtless remain a prominent part of TI's Web site. The company's research facility for the manufacture of silicon was renamed the Kilby Center. In 1990, the Kilby Award Foundation was created in his honor to identify important contributions to electrical engineering.

—*John R. Holmes*

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See also: John Bardeen; Walter H. Brattain; Robert Norton Noyce.

MARY-CLAIRE KING

American geneticist

King discovered the location for a gene that is responsible for some cases of breast and ovarian cancer, thus proving that the disease can be linked to heredity.

Born: February 27, 1946; Evanston, Illinois
Primary fields: Biology; genetics; medicine and medical technology
Primary inventions: *BRCA1* and *BRCA2* cancer gene identification; DNA profiling to identify human remains

EARLY LIFE

Mary-Claire King was born in Evanston, Illinois, on February 27, 1946, and grew up in nearby Wilmette, on the North Shore of Lake Michigan near Chicago. Her father, Harvey W. King, was an executive at Standard Oil of Indiana, chiefly responsible for labor relations. Like most other women of that era, Mary-Claire's mother, Clarice, was a homemaker, though she did work for the War Labor Board during World War II.

As a child, King liked puzzles. When she found that puzzle-solving often demanded mathematical skill, she developed an interest in that subject, even though she soon realized that it was considered an area in which only boys excelled. She was not drawn to science, however. At the prestigious New Trier Township High School, which she attended, science was not the exciting subject it became during the Sputnik era, when King's younger brother Paul was there. However, as a teenager, King witnessed her best friend in excruciating pain, dying of a kidney tumor, and that experience later impelled her toward medical research.

After graduating from New Trier, King went to Carleton College in Minnesota, majoring in mathematics. In 1966, when she was nineteen, she received her bachelor's degree, graduating Phi Beta Kappa. King then enrolled in graduate school at the University of California, Berkeley, planning to earn her Ph.D. in biostatistics, which she knew would be useful in medical research. However, a course she took from the famous geneticist Curt Stern aroused her interest in genetics, and she promptly changed her major. During the Vietnam War era, King became involved in the protest movement, finally dropping out of school to work with consumer advocate Ralph Nader. Discouraged because her scientific experiments were not working out, King considered accepting Nader's offer of a job in Washington, D.C. Fortunately, her friend Allan Wilson, a professor of biochemistry and molecular biology, persuaded her that disappointments are inevitable in scientific research, and she joined Wilson in a project comparing the genetic makeup of chimpanzees and humans, which became the subject of her dissertation. Their conclusion, that humans and chimpanzees are 99 percent genetically identical, placed the researchers on the cover of the April, 1995, issue of *Science* magazine.

King was awarded her doctorate in 1973. That same year, she married Robert Colwell, a zoologist, and they went to Santiago, Chile, to teach at the Universidad de Chile. However, following the assassination of President Salvador Allende in a military coup in September of that year in which many of their friends and students were brutally murdered, Colwell and King fled the country. The couple had a daughter, Emily, but they were divorced when she was five. King's subsequent experiences as a working single mother made her an advocate for women in the workplace.

LIFE'S WORK

Back in the United States, King spent a year at the University of California, San Francisco. At that time, she began looking for a gene that would account for multiple cases of breast cancer in the same family. In 1976, she joined the epidemiology faculty in the School of Public Health at the Berkeley campus. There, she continued to work on her research project. Finally, in 1990, she announced that she had identified the chromosome involved in the cancer and suggested the approximate location of the gene, which she named *BRCA1*.

In 1983, King was approached by a group of Argentine grandmothers whose sons and daughters had been murdered after the military coup of 1975. The grandmothers needed a geneticist to find their grandchildren, many of whom had been taken by military families and passed off as their own. King was able to find dozens of the children and return them to their families. She was also able to identify the remains of some of the young people who had been killed, thus aiding prosecutors in bringing criminal actions against the murderers.

In the 1990's, King decided to turn her talents to AIDS research. Her goal was to assess the role of genetics in the reaction of different individuals to the same disease. King had also become interested in the genetic causes of deafness. She created a team that included both Israeli and Palestinian scientists, thus demonstrating that political antipathies need not stand in the way of scientific progress.

In 1992 and again in 1999, King received the Susan G. Komen Foundation Award for Distinguished Achievement in Breast Cancer. In 1993, she was named a fellow of the American Association for the Advancement of Science. In 1994, she received the Clowes Award for Basic Research from the American Association for Cancer Research. That year, the American Cancer Society also named her the first recipient of the Walt Disney Research Professorship for Breast Cancer.

In 1995, King moved to the University of Washington in Seattle as a professor of medical genetics and genome sciences. She brought with her not only her own considerable research funds but also twelve assistants from her Berkeley lab, all of whom were supported by federal grants and fellowships. King worked with the Human Genome Project, whose goal was eventually to map all the human genes. Her lab focused on familial breast and ovarian cancer as well as prostate cancer. King also became an active participant in the Human Genome Diversity Project, which involved the study of genetic material from a number of distinct populations. These studies could reveal why certain groups are more susceptible to specific diseases than other groups. The studies will also help scientists to trace migration patterns and understand linguistic variations. Using mitochondrial sequencing, the researchers believe that in time they will be able to trace all humanity back to a common ancestor in Africa, called the "Mitochondrial Eve."

In 2004, King received the Genetics Prize of the Peter Gruber Foundation. In 2005, she was honored by being elected a member of the prestigious National Academy of Sciences. The following year, she received the Heineken Prize for Medicine from the Royal Netherlands Academy of Arts and Sciences for her work on breast cancer and the Weizmann Women and Science Award for her research in genetics. In 2008, she was given an honorary doctorate from Tel Aviv University.

BRCA1

Though her colleagues scoffed at the idea, Mary-Claire King believed that there could be a genetic cause for breast cancer. In 1974, she launched on a painstaking process that would take her two decades to complete. First, she studied the family histories of 1,579 women who were diagnosed with breast cancer, looking for other instances in their immediate families or in prior generations. In some 15 percent of those cases, she found that there were indeed other cases of the disease in the same family. King then collected blood from the families she had identified and started looking at chromosomes. A new technological development in the early 1980's made her work much easier. Deoxyribonucleic acid (DNA) could now be extracted from blood samples, making it possible to spot a marker in one person's DNA that was identical to a marker in the DNA of another family member with cancer. After examining more than 180 markers, King was sure that she had found her pattern. She now knew that the gene she had been seeking was located on chromosome 17. In October, 1990, at the annual meeting of the American Society of Human Genetics in Cincinnati, Ohio, King presented her findings. She named the first breast cancer gene to be discovered "*BRCA1*," which stood for "breast cancer," but privately she liked to think of them as a tribute to Berkeley, the university where she had pursued her research for so many years.

However, though she knew approximately where the gene was located, King had not yet isolated *BRCA1*. Her announcement impelled a number of other research teams into a frantic effort to find the gene. It was finally identified in 1994. Ultimately it was cloned, but not by King. However, by identifying *BRCA1*, King proved that breast cancer could be inherited; thus, King made it possible for individuals at risk to spot symptoms of the disease early in its development and for researchers to find out exactly how genetic breast cancers develop. King's discovery also encouraged geneticists to see whether other diseases that, like breast cancer, had previously been linked primarily to the environment could be inherited. Moreover, by discovering the location of *BRCA1*, King made an important contribution to an area of genetics that could result in revolutionary treatments for various diseases. When scientists know how genes work, gene therapy (the insertion of DNA into an individual's cells to treat a disease) can become a real possibility. Finally, King's pioneering research encouraged scientists, as well as the general public, to focus their attention on breast cancer and to take the necessary steps to defeat it.

IMPACT

King's three major discoveries in the field of genetics have advanced scientific knowledge and significantly affected human life. By finding that the genomes of human beings and chimpanzees are nearly identical, she bolstered the theory that the two species had a common ancestor and modified the estimate of when the two diverged, thus altering conventional assumptions about evolution.

By discovering *BRCA1*, the gene on chromosome 17 that is linked to breast cancer and also to ovarian cancer, she proved that some of these cancers are inherited. Her work stimulated research into the genetic basis of breast cancer, resulting in the isolation of *BRCA1* and the identification of another breast cancer gene, *BRCA2*. King's discovery not only aroused interest in breast cancer research but also impelled geneticists to initiate studies of other diseases, in the hope that they might find similar familial links; moreover, King and her colleagues could now investigate the possibility that gene therapy, the insertion of DNA into an individual's cells to treat a disease, might be used in the treatment of cancer. King's third contribution to science and to society was her application of DNA technology in human rights causes. She first used DNA sequencing to locate persons "disappeared" during Argentina's "dirty war" in the 1970's and 1980's, and later she also utilized the methods she had developed in order to identify the remains of victims of the repressive regime. King's technique became the standard method of identifying human remains, whether for human rights organizations investigating genocide or for government agencies dealing with disasters. Thus, the work of this dedicated scientist has impacted the lives of countless human beings.

—*Rosemary M. Canfield Reisman*

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See also: Stanley Norman Cohen; Raymond Damadian; Robert Charles Gallo; Alec Jeffreys; Kary B. Mullis.

EWALD GEORG VON KLEIST

German physicist

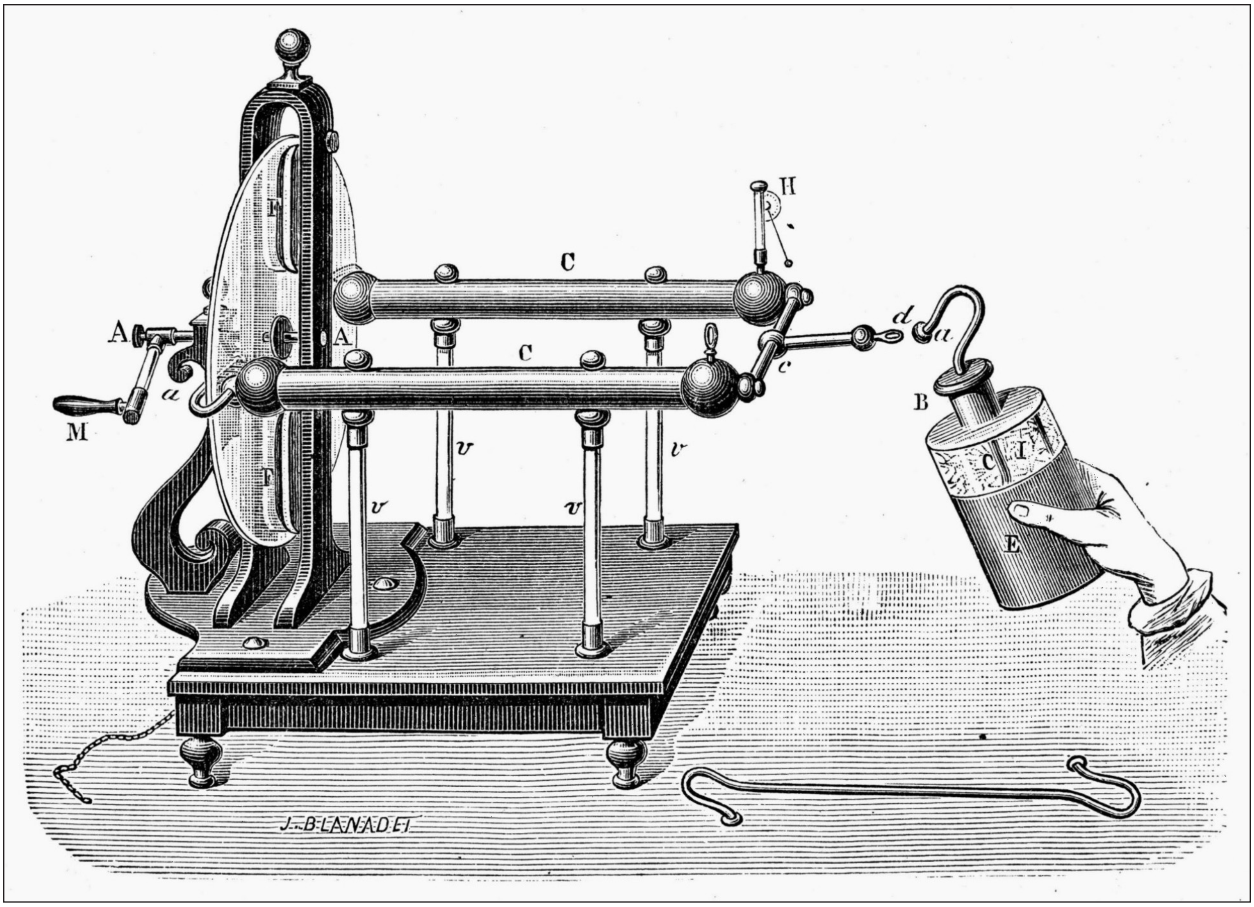
Von Kleist developed the Leiden jar, an early device that stored electricity by accumulating electricity generated by a primitive friction machine in a glass container. This device is the ancestor of the capacitor, which is used in modern electrical and electronic equipment.

Born: June 10, 1700; Vietzow, Farther Pomerania, Prussia (now in Germany)
Died: December 11, 1748; Köslin, Pomerania, Prussia (now Koszalin, Poland)
Also known as: Ewald Jürgen von Kleist
Primary field: Physics
Primary invention: Leiden jar (precursor of the capacitor)

EARLY LIFE

Ewald Georg von Kleist (A-vawlt GAY-ohrk fahn klist), a German jurist, Lutheran cleric, and physicist, was born in 1700 in Farther Pomerania, a region in north-central Europe on the Baltic Sea between what is now Poland and Germany. Little is known of his early life beyond the fact that he was born into an upper-class family; his father was a Prussian district manager. Von Kleist enjoyed a reasonably comfortable childhood and youth and was well educated.

In the 1720's, he attended first the University of Leipzig in Germany and then the University of Leiden in the Netherlands, where he studied jurisprudence. His interest in science was stimulated by the experiments of one of the professors in Leipzig, Georg Matthias Bose. Bose, intrigued by electricity, as were many other upper-class



A Leiden jar is charged by a Ramsden electrostatic generator. (The Granger Collection, New York)

Europeans, explored the phenomenon of igniting flammables with sparks generated by electrical friction machines. Much of Europe had become enthralled by the diversions produced with gadgets and the party jokes that used static electricity. However, those more serious-minded individuals saw the potential of electricity to accomplish more worthwhile benefits than mere entertainment and were interested in finding ways to harness its power for practical uses. Von Kleist was one of those who, after observing the demonstrations, developed an interest in serious experimentation. He was particularly interested in those demonstrations in which alcohol, gunpowder, and turpentine were ignited by electrical sparks.

When he completed his education at the University of Leiden, he returned home to Pomerania and became a dean (bishop) of a cathedral chapter of Camin, where he remained from 1722 to 1745. His curiosity about electricity continued, and his aim was to find a way to conserve or accumulate an electrical charge so that it could be used later.

LIFE'S WORK

By the 1740's, electricity as a means of entertainment and a scientific phenomenon had captured the interest of large segments of European society. Professor Bose at the University of Leipzig continued conducting experiments that generated considerable interest in electricity's potential. Frederick the Great, king of Prussia, opened the Berlin Academy of Sciences in 1744, where experiments in electricity were conducted. About the time von Kleist was experimenting with capturing electrical charges and attempting to increase their power, a Dutch professor at the University of Leiden named Pieter van Musschenbroek was working on a project with the same goal. Both men would independently arrive at the same discovery. Musschenbroek made his in January, 1746, but von Kleist had made his discovery two months earlier.

Working with knowledge of the experiments of contemporaries such as Bose and Johann Krueger, von Kleist began his attempts to increase the strength and reliability of the electrical flare. His discovery was probably an accident. According to his account of the experiment, he inserted an iron nail into the cork sealing the opening of a handheld glass jar. The jar contained a liquid, variously supposed to be alcohol, mercury, or water. Von Kleist connected the nail to his friction machine to electrify it. He found that the electrical charge could be retained for several hours. Even more astonishing, the charge retained by the jar could be strong enough to ignite wine or other spirits as successfully as the friction machine had done. Von Kleist also received a severe shock when, while holding the glass jar in one hand, he touched the nail with his other hand. He noted that he got a shock only when both hands were on the jar. (This was an example of closed circuitry, a concept unknown at the time.) When his hands touched only the nail, no shock was felt. The shock was strong enough to numb his arm and shoulder. When he touched the nail in the jar to another object, the jar discharged the stored electricity and produced a spark. The device's spark lasted long enough to make a noticeable light in the room.

When he was finally satisfied with the results of his experiment, he wrote to several professors and Berlin Academy members describing the experiment and its effects. They tried to replicate his experiment, but most of them were unsuccessful. Those few who managed to perform the experiment successfully shared the news among themselves but apparently did not widely disseminate the discovery. On the other hand, news of the same discovery by the more famous Musschenbroek quickly reached several countries. Therefore, Musschenbroek's discovery of the Leiden jar and his more thorough investigation of the jar's potential was more widely known for many years. Nevertheless, von Kleist was eventually recognized as the discoverer of this primitive capacitor.

Though the device von Kleist discovered was once called the "Kleistian jar" in his honor, a French scientist, Abbé Nollet, coined the term "Leiden jar," named for Musschenbroek's hometown and the Dutch university where he taught. After its discovery, the Leiden jar was used to put on spectacular demonstrations for spectators. One demonstration that created a particular stir was prepared for the king of France: A regiment of soldiers was lined up, linked together with pieces of wire. Then an electrical charge was sent them, causing them to simultaneously leap into the air, to the amazement of onlookers.

After von Kleist's career as dean of a cathedral chapter at Camin ended in 1745, he went on to become president of the royal court of justice in Köslin. He died there in 1748.

IMPACT

The Leiden jar was significant to eighteenth century scientists as well as to those who recognized its potential beyond entertainment. By 1752, numerous publications had proclaimed the many uses for the jar in several fields, especially medicine. By 1789, as many as seventy applications in medicine alone had been ascribed to the jar.

Over time, as scientists learned about the concepts of charge, current, and capacitance, the jar became increasingly important for research. It made possible the production of electrical charges that had greater power than any previously produced. As its power was demonstrated to ever more philosophers and scientists, its advantages beyond entertainment were brought to the attention of leaders of different countries, who proceeded to support more research.

Eventually, experimenters used the jar to develop the capacitor, a device with the ability to store unused electrons and ultimately deliver electric power over great distances. The capacitor is an integral element of today's radios, televisions, and other electronic devices. The jar itself is still used today in laboratories for experiments and demonstrations.

—Jane L. Ball

Von Kleist's Leiden Jar

Eighteenth century "electricians," searching for ways to increase the electrical charge they could generate from frictional sources, hoped to create a device to conserve significant quantities of electricity to be used at a later time. Ewald Georg von Kleist's Leiden jar accomplished just this. It was a simple device, originally a narrow-necked glass jar half-filled with water (though it was soon found that such thin-necked glasses were easily broken by the powerful electric shocks generated). The inside and outside surfaces of the jar were coated with a conductive metal foil. The glass served as the dielectric (a nonconductive material), though initially it was believed that it was the water that prevented the conduction of electricity. A cork placed in the top of the jar as a stopper had a metal wire or chain and a nail or metal rod driven into the cork in a way that allowed the wire or chain to rest in the water. The nail or metal rod was then hooked to an electrical friction machine, a static generator, cranked by hand to produce and deliver an electrical charge. The jar, thus primed, would hold two equal but opposite charges that, when connected to another wire, would produce a spark or shock.

Von Kleist's account of his Leiden jar experiments states that the device was able to produce an electric charge that lasted long enough for him "to walk sixty paces" around the room where he conducted tests. Anyone holding the device, if touched by another, would receive a shock "so strong . . . [that] both arms and shoulders [would be] shaken thereby." His experiments demonstrated that the electrical charge could be retained even for hours and could be strong enough to ignite wine or other spirits. The Leiden jar's capabilities became so widely appreciated that within a few years, Benjamin Franklin used one in his kite-flying experiment.

The Leiden jar was first a glass vial, but its more familiar form is a coated jar with a brass rod connecting the inner coating with the outer coating. It became useful to experimenters in electrical research because its compact size made it easier to move about than electrostatic generators. In modern times, it is used most often for classroom and laboratory demonstrations and for experimental purposes. It is significant as the forerunner of the capacitor, used in electric lighting and such electronic devices as television sets and radios.

Further Reading

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See also: Benjamin Franklin; Pieter van Musschenbroek; Alessandro Volta.

MARGARET E. KNIGHT

American mechanical engineer

Credited with about ninety inventions and twenty-two patents, Knight is best known for a machine that made square-bottom paper bags, which continue to be widely used in grocery stores and in homes.

Born: February 14, 1838; York, Maine
Died: October 12, 1914; Framingham, Massachusetts
Also known as: Margaret Ethridge Knight (full name); Lady Edison
Primary fields: Business management; household products; packaging
Primary invention: Paper bag machine

EARLY LIFE

Margaret Ethridge Knight was the daughter of James and Hannah Knight. Born in 1838 in York, Maine, Margaret later moved with her family to Manchester, New Hampshire. She always displayed an interest in subjects associated with males and claimed that she would rather have a jackknife than a doll. At a young age, she developed a reputation as a tomboy, and her inventiveness pleased her brothers, for she made kites and other kinds of toys for them, while she devised a foot warmer for her mother. Her father gave her free access to his tools, and when he died, while she was still a child, they were passed on to her. Her mother was left with the task of rearing her and her two brothers in a mill town.

Manchester, which was named for an industrial town in England, in Knight's time employed fifteen thousand people in its factories and produced 360 miles of cotton cloth a day. Her brothers worked in a mill, and Knight, a very serious child, learned about the importance of machinery when she brought her brothers their lunches. She came to realize that manufacturing was a dangerous way of earning a living. At the age of twelve, she witnessed a young working girl injured in the Amoskeag Mill by a shuttle that came loose from a loom. This accident inspired Knight to develop a device that could quickly stop a loom, and eventually all looms in Manchester were provided with them. She also had the experience of working in a cotton mill herself. She was not the first woman to receive a patent, as has sometimes been claimed, but she learned, while still a teenager, about patents and how to prepare them.

LIFE'S WORK

Knight's education took her through secondary school; then, like many single young women, she had to find a job. She was a tall and strong young woman with great determination to improve the efficiency and safety of factories. In 1867, while working at Columbia Paper Bag Company in Springfield, Massachusetts, she began to devise a machine that would produce bags with square bottoms so that the user did not need to hold them erect. A man named Charles Annon also was interested in this process, but Knight suspected that Annon was copying her work by spying on the machinist she hired to make her model. Annon argued in his defense that as a woman she could not have understood the complexities of such a machine. Examination of her notebooks and diary proved otherwise, and she won her claim in court in 1870 and earned her patent. Shortly thereafter, she cofounded the Eastern Paper Bag Company in Hartford, Connecticut.

From that time on, Knight invented many items. In 1883, she devised a skirt protector, which was a shield that fit between the outer and inner walls of the elaborate skirts that women wore at the time. It protected the inner surface from rain, snow, and dirt and was secured by a waist belt. The following year, Knight invented a clasp for holding together robes or textile fabrics.

By 1889, Knight was living in South Framingham, Massachusetts, where she would spend the rest of her life, and had turned her attention to machines for cutting shoes. She devised a machine for cutting India rubber and other materials used for the soles of boots and shoes. The machine consisted of an endless apron, or belt, with a series of tablets, or beds, flexibly connected and able to move horizontally beneath a pattern and a blade that had a vertical reciprocating movement. The material would be clamped on an apron, and a complete sole would be cut out on each of the tablets. The apron would carry both the soles and waste material out of the machine. In connection with shoemaking, Knight also patented a numbering mechanism. Working with a man named Charles S. Gooding in 1894, she designed a machine for imprinting or stamping numbers or other characters on products such as boots and shoes.

Also in 1894, Knight filed a patent for a new design of window sash. Realizing the difficulty of cleaning window panes by merely raising and lowering the sashes, she devised a frame whose sashes did not simply operate vertically but would swing horizontally outward. This improved window frame and sash, now very common, seems not to have come into frequent use until a number of decades later.

THE PAPER BAG MACHINE

Before Margaret E. Knight's paper bag device, no machine was able to fold a web of paper into a tube and then, by the continuous operation of the machine, so operate upon the leading end of the tube to form automatically the diamond fold, which is the basis of the flat-bottomed bag.

The frame of the machine must be of a suitable shape to sustain the parts. The indefinitely long web of paper from which the bags are made is drawn from a roll so suspended that it can be unwound and supplied to the machine as fast as required. This web is folded about a former with the lap upon the upper side. The pasting is done by another machine. This machine folds a web of paper into a tube and operates on the leading end of the tube, carrying it forward to form the necessary diamond fold.

After a sufficient length of the tube is cut for a bag, the diamond-folded end of the piece of tube is folded transversely and pasted in the form required to produce a satchel-bottom bag. The novel part of Knight's machine she called a "finger," the purpose of which is to open one end of the paper tube, lay it back upon itself, and form the diamond fold. The invention also has a feeding mechanism to move the tube forward so that the finger can enter the open end of the tube as it is being led forward and, by its action within the tube upon one ply thereof, lay the ply back in the opposite direction of the movement of the tube determined by the feeding mechanism. The invention also has a follower that projects beyond the front end of the former and keeps the two plies of the tube separated, so that the leading end of the tube may be readily entered to permit one ply of it to be raised in the formation of the diamond fold.

The machine contains a folder to ensure a straight transverse fold in but one ply of the tube and to determine the line or direction of the fold as that ply is turned outward and back by the finger. The machine also has a blade and a pair of rolls to clear the bag from the machine. The blade rests and moves in a curved guideway that directs the blade to move downward and forward, and then backward and upward, traveling at about the same velocity of the tube-feeding mechanism. Descending upon one end of the diamond fold, it creases it transversely and forces the bag into the bight of the rolls, which carry it away. One of Knight's bag machines may be seen today in the Smithsonian Museum of History and Technology.

By the end of the century, Knight was working on compound rotary steam engines, and in 1902 she patented an improved engine with a new arrangement of cylinders and a new construction of the valve that supplied the steam. She followed this the next year with a new deployment of pistons and their abutments to prevent vibration of the engine. In 1903, along with John M. Benjamin, she patented an automatic tool for boring or planing concave surfaces or the surfaces of cylindrical chambers in rotary engines. She continued to work on improvements in internal combustion engines. In 1910, when she was in her early seventies, she patented a spring wheel with a resilient hub to increase ease of motion in automobile tires.

Knight's working life extended nearly to her death. Called "Lady Edison" by her supporters, she worked in a variety of fields, devising items for women, for households, and for factories. She suffered from pneumonia in 1914 and died on October 12 at the age of seventy-six.

IMPACT

It is sometimes difficult to determine how long or how well some of Knight's inventions worked. She assigned her improvements on engines to the Knight-Davidson Motor Company in New York. Inventions such as her skirt shield would of course not outlast the full skirts of the late nineteenth century, and steam engines that she worked to improve were rendered obsolete by electrical engines. She turned to the needs of the day over a period of more than forty years while the manufacturing world saw many changes. As someone who had almost reached senior citizen status when automobiles began to appear, she ended her career working on improvements in automobile wheels.

Although it is actually simpler than some of her other machines, the paper bag machine has been Knight's most famous invention. Today, more than seven thousand machines in the world produce flat-bottom paper bags, and despite the fact that many plastic bags are used in grocery stores, customers continue to ask for flat-bottom bags and even to buy them if grocers do not supply them with their orders. People continue to use paper bags around their homes.

Despite the patents that Knight was granted, her labor does not seem to have been well rewarded. When she died in 1914, her estate was valued at less than $300. Her work has not been forgotten, however. In 2006, she was inducted into the Paper Industry International Hall of Fame.

—*Robert P. Ellis*

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See also: Jacques Edwin Brandenberger; Richard G. Drew; Patsy O'Connell Sherman.

WILLEM JOHAN KOLFF

Dutch American physician

A visionary in the field of artificial organ engineering whose groundbreaking research led to revolutionary developments in both cardiac and pulmonary treatment, Kolff designed the first artificial kidney, a dialysis machine that cleaned the blood of patients in renal failure.

Born: February 14, 1911; Leiden, the Netherlands
Died: February 11, 2009; Philadelphia, Pennsylvania
Primary fields: Biology; medicine and medical technology
Primary invention: Dialysis machine

EARLY LIFE

Willem Johan Kolff (WIHL-uhm YOH-hahn kohlf) was born on Valentine's Day, 1911, in Leiden, the Netherlands. His father, Jacob, was a respected physician who had opened a tuberculosis sanatorium. As a child, Willem loved to watch carpenters, intrigued by their methodical constructions, and he loved animals (he wanted to be a zoo director). He resisted his father's advice to pursue medicine because he did not want to watch people die. In the time before antibiotics, tuberculosis patients often faced agonizing deaths. An average student (he was dyslexic), Willem was accepted for medical studies in 1930 at the prestigious University of Leiden largely through the influence of his father. From 1934 until 1936, Kolff was posted in the university's anatomical pathology department, where he first studied the structural and compositional changes in diseased organs.

After graduating in 1938, Kolff initially went into teaching, joining the medical faculty at the University of Groningen, among the oldest and most respected research universities in Europe. During his stint there, Kolff, after attending a twenty-two-year-old patient who agonized before succumbing to kidney failure, reviewed the specific problems faced by such patients. For these patients, the kidneys could no longer filter liquid wastes from the blood, allowing the accumulation of waste products normally removed in the urine. The resulting accumulation, called uremia, represented a potentially lethal problem for the body. More than twenty years earlier, medical researchers investigating short-term kidney failure had suggested the theoretical workability of blood dialysis as a way to treat these patients, the principle in which the blood would be passed through a semipermeable membrane to a solution with a lower concentration. It would be a way to cleanse the blood, like some kind of external, temporary kidney. After the anticoagulant heparin became available in the mid-1920's, experimental research into dialysis machines began to find success—save that the process in the experimental models was quite slow (sometimes more than an hour) and the availability of the heparin was scarce as Europe moved toward World War II.

LIFE'S WORK

Following the Nazi invasion of Holland in spring, 1940, Kolff, a passionate opponent of the occupation, quickly completed his certification as an internist and promptly left Groningen when the hospital was restaffed with Nazi sympathizers. (He would return after the war to complete his Ph.D. in 1946.) Kolff relocated to a small hospital in

Kampen where he was the sole internist. Quickly recognizing the dire circumstances of the war, Kolff went about directing the establishing of what would be Europe's first blood bank to make transfusions safe and available for both soldiers and civilians. He never entirely abandoned dialysis research, however, though materials were in short supply. As early as 1941, he set up a working model (using more than fifty yards of sausage casing to contain and filter the patient's blood). Not entirely surprising, the first patients Kolff worked with died (blood coagulated too quickly). He reworked the design and, in 1945, a woman in a coma from kidney failure was put on the machine and lived. After making refinements in the design, Kolff refused to patent it, believing it unethical for a doctor to make money from such devices. Rather, after the war, he circulated the design freely to researchers around the world. Eager to work with the research resources in the United States, Kolff joined the Cleveland Clinic Foundation in 1950—by then, his dialysis machines were routinely saving hundreds of lives.

THE ARTIFICIAL KIDNEY MACHINE

Willem Johan Kolff's 1941 prototype of the kidney dialysis machine, crude as it may appear, testifies to the vigor and improvisational resourcefulness of scientific ingenuity applied to a specific problem, how with limited resources a researcher/technician can nevertheless realize an ambitious premise. Although the idea of dialysis had been proposed earlier, few medical researchers before Kolff looked favorably on the idea of actually draining the blood from the body as way to cleanse it of the damaging buildup of toxic materials (principally urea and other salts) that regularly resulted in the death of kidney patients. Kolff maintained that short-term external treatment of the blood could help sustain a patient until the damaged kidneys returned to full effectiveness. Eventually, his design would allow long-term care for patients with renal failure, adding years to their lives. Add to that the fact that Kolff worked under the extreme conditions of an occupied country during wartime with its resources severely curtailed, and the experimental model of the dialysis machine becomes a monumental expression of the research imperative.

Kolff was certain that toxic blood could be filtrated through a semipermeable membrane, agitated in a saline solution to purify it, and then returned to the body. His work establishing the wartime blood bank helped him understand how to handle blood outside the body. In initial attempts, the patient's wrist artery was slit and the blood extracted fifty milliliters at a time. The blood was fed through sterile tubing of sausage casings made of cellophane (a new substance at the time) that served as the semipermeable membrane and then agitated in a large drum that contained a sterile solution of saltwater. In so doing, as the blood passed through, impurities would be filtered out, a process that took about five minutes. The casing's microscopic pores did not allow essential red and white blood cells to fit through. Rather, the agitation in the drum allowed the salts and urea to flow through the membrane and then harmlessly out into the solution, thus removing the impurities much as a functioning kidney would. The problem of returning the treated blood proved tricky, particularly before stronger anticoagulant drugs were readily available. Kolff designed a recovery system by jury-rigging a pump based on the design of the water pump used in Ford motor engines. He implemented his design using two orange juice cans and a pump from an old washing machine. The blood was essentially pumped back into the body gently—and the process then repeated with fifty more milliliters. The process was time-consuming and, at least initially, risky (the first sixteen patients died), but Kolff resolutely set about improvements that made the machine ultimately efficient and safe.

First as professor of clinical investigation and later as the science director of the artificial organs program at the Cleveland Clinic, Kolff turned his attention to pulmonary research, specifically problems facing surgeons in heart bypass procedures. Initially, he worked on the team that in 1955 developed the membrane ox ygenator, a kind of artificial lung used to add oxygen to and remove carbon dioxide from the blood, a device that could be used in bypass surgery when the lungs were disabled. Once again, Kolff refused to patent his device.

The experience with pulmonary care caused Kolff to consider the possibility of developing a mechanically efficient implantable artificial heart, a revolutionary idea he conceived nearly two decades before the technology would be available to realize it. However, in 1957, a prototype kept a laboratory dog alive for nearly ninety minutes.

Kolff maintained his appointment at the Cleveland Clinic until 1967. With ambitions to start an entire institute expressly for biomedical engineering, he accepted an appointment at the School of Medicine at the University of Utah. There, as head of the Division of Artificial Organs and the Institute of Biomedical Engineering, he pursued opportunities for significant research monies and, with a massive research team of 175 doctors, surgeons, engineers, and chemists over the next decade, pursued cutting-edge investigations into developing artificial eyes, ears, and arms.

However, it was research into the artificial heart that defined Kolff's career at Utah. On a research team directed jointly with Dr. Robert Jarvik, Kolff pioneered refinements in the mechanical device and experimented on more than two hundred lab animals and dozens of cadavers. Kolff headed the surgical team that successfully implanted the soft-shell mushroom-shaped device into a patient named Barney Clark on December 2, 1982. The so-called Jarvik-7 heart functioned for 112 days before Clark's death from complications from organ failure, although the heart was still working. During the four months after Clark's procedure, amid tremendous international interest in the operation, Kolff was compelled to defend the artificial heart against moral and ethical opposition that saw the procedure as toying with the so-called center of human emotions and personality, upsetting the "natural" order of life and death, and denying the patient any quality of life. Kolff brushed aside such objections, citing the Clark operation as a threshold procedure designed to provide researchers data for long-term cardiac care.

Kolff continued to research artificial organ technology, even after his retirement in 1997 (at the age of eighty-six). He was particularly interested in an artificial lung that would be worn on the outside and a similarly portable kidney to make dialysis convenient. He garnered many international honors for his commitment to bioengineering, most notably the Albert Lasker Award for Clinical Research in 2002. In 1985, he was inducted into the National Inventors Hall of Fame, and in 1990 he was listed among *Life* magazine's most important Americans of the twentieth century. He died on February 11, 2009, at the age of ninety-seven in a retirement home in Newton Square in Philadelphia, Pennsylvania, where he had moved to be near his son.

Impact

It is impossible, of course, even to estimate the number of lives that Kolff's biomedical engineering innovations affected. His dedication to the hands-on work of designing and testing mechanical organ devices was fostered by his early encounters with the human face of suffering that taught him that the responsibility of doctors was not to manage but rather to alleviate that pain. That is his legacy. Since the mid-1950's, dialysis alone has guaranteed a quality of life to millions of patients worldwide struggling with renal end failure who must wait for transplant surgery. Although the technology of the artificial heart and lungs has yet to catch up to Kolff's ambitious vision, his theoretical work, stubborn diligence, and painstaking trial-and-error experimentation on such artificial organs (work done across more than seven decades) position him among the most important medical researchers of his era, remarkable for the sheer reach and variety of fields Kolff tackled.

More than his groundbreaking advances in medical technology, Kolff emerged as a kind of pragmatic conscience of the biomedical engineering field, a field routinely accused of lacking any humanitarian agenda in its rush to mechanize the body and play God. His life has provided an exemplum of a passionate conscience. Not only his courageous resistance to the Nazi threat and his work under inhospitable conditions of war-torn Holland but also his insistence later that his designs be made readily available to the international community without benefiting him financially serve as a striking example of selfless dedication. He pursued the application of engineering ingenuity to medical problems without being distracted into arguments over the ethics of such work—rather, he understood that the role of medical researchers was to solve problems. Not surprisingly, he devoted enormous amounts of time for more than twenty years to campaigning with tireless vigor for a variety of public forum issues from prison reform to public education, certain that solution-thinking could be applied to social issues as well.

—*Joseph Dewey*

Further Reading

Broers, Herman. *Inventor for Life: The Story of W. J. Kolff, Father of Artificial Organs*. Kampen, the Netherlands: B & V Media, 2007. Biography that stresses Kolff as a maverick and focuses primarily on his wartime experience constructing the first dialysis machine. Written by a respected Dutch journalist, the book provides an anecdotal history of Kolff from friends and family. Written with the cooperation of Kolff.

Heiney, Paul. *The Nuts and Bolts of Life: Willem Kolff and the Invention of the Kidney Machine*. Charleston, S.C.: The History Press, 2003. Definitive chronicle of Kolff's groundbreaking theoretical work and construction of the first dialysis machine. Emphasizes Kolff's knack for problem-solution thinking and his unshakeable belief in the medical profession's obligation to relieve suffering as his guiding premise. Written with the cooperation of Kolff.

Montaigne, Fen. *Medicine by Design: The Practice and*

Promise of Biomedical Engineering. Baltimore: The Johns Hopkins University Press, 2006. Articulate defense of biomedical engineering, with generous anecdotal evidence of its effectiveness. Although its discussion of dialysis is slight, the book examines with some detail the evolution of the artificial heart and Kolff's role in the Clark operation.

Tracy, Kathleen. *Willem Kolff and the Invention of the Dialysis Machine*. Bear, Del.: Mitchell Lane, 2002. Geared for high school readers, Tracy's work offers a clear and helpfully illustrated explanation of Kolff's original design and the evolution of his basic theory into the dialysis machines of today. Quite a heroic depiction of Kolff; stresses the difficult wartime conditions under which he worked.

See also: Charles Richard Drew; Robert Jarvik; Paul Winchell.

ROSCOE KOONTZ

African American health physicist

Koontz was a pioneer in the field of health physics, a discipline concerned with protection from ionizing radiation. Many of the nuclear safety procedures he helped to implement are still used today.

Born: December 16, 1922; St. Louis, Missouri
Died: May 17, 1997; Richland, Washington
Primary fields: Chemistry; medicine and medical technology; physics
Primary invention: Pinhole gamma-ray camera

EARLY LIFE

Roscoe Koontz spent his youth in the residentially segregated city of his birth, St. Louis, Missouri. Unlike many of his peers who sought employment upon graduation from Vashon High School, one of the city's racially segregated public schools, Koontz opted to continue his education. With few opportunities available for blacks, Koontz chose to remain close to home as he considered possible career options. He enrolled at Stowes Teachers College in the St. Louis area. Founded in 1890 as a normal school for future black elementary teachers, Stowes offered Koontz the opportunity to consider his future plans. When he made up his mind, Koontz discovered that he wanted something more than the routinized life of an educator.

With one year of college under his belt, Koontz enlisted in the Regular Army Reserve Corps in 1942 and remained on active duty in this capacity until the end of World War II. Military service afforded Koontz the opportunity to travel outside his home state as well as the chance to take advantage of federally funded educational opportunities at West Virginia State College, where he received training in a pre-engineering program. After the war, Koontz attended Tennessee State University, a historically black college, where he graduated with a degree in chemistry.

LIFE'S WORK

In 1948, Koontz participated in the University of Rochester's Atomic Energy Health Physics Fellowship Training Program. Koontz flourished under the rigorous training he received at the upstate New York school and soon realized that he possessed considerable aptitude for detailed scientific investigation. While at Rochester, he began researching methods for safely harnessing ionizing radiation, an interest that he would make his life's work.

After completing the Rochester program, Koontz entered the field of health physics, which concerns the safe use of radiation in various settings. Koontz would focus mostly on nuclear reactor safety. Health physics was in its infancy when Koontz entered the field, and many of the professional standards for the discipline were established by Koontz and other early practitioners. A considerable number of the early nuclear safety procedures and much of the early radiation-detecting equipment employed are used to this day.

After receiving rudimentary training in health physics, Koontz relocated to Los Angeles, California, where he began work at Atomics International, a division of North American Aviation, at its Canoga Park nuclear reactor construction and research facility. There with a team of scientists, Koontz conducted a wide array of studies into reactor safety and radiation detection. His employment at the company coincided with the most productive phase of his professional career, during which his research team set the standard by which all nuclear facilities would be judged. From the 1950's to the early 1970's, Koontz coauthored scores of scholarly articles and research projects, including studies on nuclear safety, reports on the characteristics of aerosols produced by sodium fires, examinations of errors in measurements of building leakage due to dynamic temperature effects, assessments that helped to predict and control leakage through cracks and capillaries in reinforced concrete buildings used to house reactors, and assorted items related to liquid-metal fast-breeder reactor accidents. During this period, Koontz regularly attended professional meetings relevant to his field, such as the U.S. Atomic Energy Commission's Air Cleaning Conferences, to learn from his peers and to share his research with others.

In the 1970's, Koontz spent less time researching as he assumed control of all contract work on portions of the massive Clinch River Breeder Reactor project at Oak Ridge, Tennessee, under the direction of the Atomic Energy Commission. Sodium-cooled fast-breeder reactor technology was then in its early stages. In theory, the facility would "breed" more fuel than it consumed, making it a cost-effective energy source. Developers of the Clinch River project hoped that its successful construction would serve as a prototype for other nuclear facilities across the nation. Interest in the project waxed and waned depending on the presidential administration in office and overall public support for nuclear power. Cost overruns and concerns regarding the safety of nuclear energy ultimately undermined the project. Originally fixed with a $400 million construction cost, the project's price continued to climb over the next decade. By the dawn of the 1980's, more than $1 billion had been spent on the still-uncompleted Tennessee reactor. In 1983, Congress cut funding for the project, leading to its eventual abandonment.

Despite the setback, Koontz remained with the same employer for most of his career (although North American Aviation had merged with Rockwell-Standard Corporation in 1967). Later in life, Koontz worked at Rockwell's Hanford Operations in Richland, Washington, in the Pacific Northwest. He died in 1997.

IMPACT

Koontz overcame obstacles of racism to become one of the leading figures in his chosen field, devoting his professional career to harnessing the power of nuclear energy and making it safe for public use. His research helped lay the foundation for the discipline of health physics.

During the 1980's, the U.S. government largely abandoned its support for nuclear power in part because of concerns over reactor safety. Incidents such as the 1979 partial meltdown at the Three Mile Island nuclear facility south of Harrisburg, Pennsylvania, prompted a reassessment of the nation's commitment to nuclear power. In the early twenty-first century, however, the volatile price of oil has encouraged many to reconsider nuclear energy as a viable alternative to fossil fuels. The work of Roscoe Koontz and other nuclear pioneers will no doubt play an integral role in any future U.S. plans to develop nuclear reactors.

—*Keith M. Finley*

THE PINHOLE GAMMA-RAY CAMERA

Roscoe Koontz and fellow researchers at Atomics International in Canoga Park, California, sought to produce technology that made nuclear reactors safer. As part of his ongoing research in nuclear safety and development, Koontz designed a pinhole gamma-ray camera, an imaging device capable of detecting the distribution of radionuclides (often referred to as radioactive isotopes), atoms with unstable nuclei that emit gamma rays, which make up the ionizing radiation produced by nuclear reactions. Only gamma rays traveling in a parallel direction to the device are filtered through the camera. Although Koontz originally designed his camera to detect radiation in nuclear reactors, such cameras are widely used today by medical professionals to locate tumors and other abnormal growths without exposing patients to toxic levels of radiation. Gamma-ray cameras have been used in other fields as well. The U.S. Department of Homeland Security, for example, has explored using these cameras to identify radiation in shipping containers.

Reactor development and eventual public usage depended on the work of health physicists, who often risked their own safety in pursuit of science. Years after Atomics International was absorbed by Rockwell-Standard Corporation, investigations concerning the increased cancer risk posed to employees at the Canoga Park facility as well as to the surrounding community were conducted. The long-term health effects of nuclear exposure were not fully known at the time Koontz worked, and employees in atomic industries were exposed to dangerous radiation levels.

FURTHER READING

Carwell, Hattie. *Blacks in Science: Astrophysicist to Zoologist*. Hicksville, N.Y.: Exposition Press, 1977. Carwell is a health physicist by training and an active promoter of the achievements of African American scientists. Her discussion of Koontz stems from personal communication with the scientist, who preferred to keep his achievements private.

Cember, Herman, and Thomas E. Johnson. *Introduction to Health Physics*. 4th ed. New York: McGraw-Hill, 2009. An important textbook that discusses the roles that Koontz and others played in the field of health physics. Highlights how far the discipline has come since the early days of the profession, when rules and regulations were often created on the fly.

Rovai, Alfred P., Louis B. Gallien, and Helen R. Stiff-Williams, eds. *Closing the African American Achievement Gap in Higher Education*. New York: Teachers College Press, 2007. Explores the struggles faced by black college students today, owing in part to a legacy of discrimination. Underscores how remarkable Koontz's achievements were in an era of widespread racism and state-mandated segregation.

See also: Enrico Fermi; Hans Geiger; Godfrey Newbold Hounsfield.

RAY KURZWEIL

American computer scientist and software engineer

A leading advocate for artificial intelligence, Kurzweil developed several advanced computer-based pattern-recognition technologies, expert systems for finance, music composition, and other fields, as well as electronic musical instruments.

Born: February 12, 1948; Queens, New York
Primary fields: Computer science; mathematics; music
Primary invention: Kurzweil Reading Machine

EARLY LIFE

Ray Kurzweil (KURZ-wil) grew up in Queens, New York. His parents, a well-educated secular Jewish couple involved in the arts, had escaped from Europe during the years of the Holocaust. His father, a musician, and his mother, a visual artist, encouraged his creativity, and his uncle, an engineer at Bell Labs, shared his knowledge of computers with Kurzweil. As a child, Kurzweil enjoyed reading science fiction, learned about diverse spiritual traditions, and also developed a deep concern for social justice. He loved programming, and in high school he created music composition software that could analyze the style of a given piece and generate music in the same style. Word of this achievement spread, and in 1965 he appeared on national television as a guest on Steve Allen's program *I've Got a Secret*. Following the format of the program, Kurzweil played a composition on the piano, and it was eventually revealed that his computer program had composed the piece. His project won first prize in the International Science Fair, and as a winner in the Westinghouse Talent Search, he and thirty-nine other students were honored at the White House, where they were greeted by President Lyndon B. Johnson.

Kurzweil continued to distinguish himself as a college student at Massachusetts Institute of Technology (MIT), where he earned a bachelor of science degree in computer science and literature in 1970. One of his most important teachers at MIT was Marvin Minsky, a pioneer in artificial intelligence (AI). During Kurzweil's sophomore year, he created the Select College Consulting Program, which matched high school students with colleges using a database with two million items of information about three thousand colleges. Kurzweil ran this as a business, renting time on a mainframe computer to perform the calculations, and his program was highly successful. He sold it to the publisher Harcourt Brace Jovanovich for $100,000.

LIFE'S WORK

After graduating, Kurzweil continued his work in pattern recognition, applied to the problem of enabling a computer program to recognize printed letters. This task, know as optical character recognition (OCR), had only been partially solved, because existing programs could recognize characters, but only in a few fonts. This placed severe limitations on the practical value of such systems, since text is printed in a great variety of fonts. Kurzweil founded Kurzweil Computer Products in 1974 to work on this and other technologies, and he soon succeeded in developing the first omnifont optical character recognition program. After a conversation with a blind man who was a fellow passenger on an airplane, Kurzweil realized that his OCR program could be combined with other innovations to create a useful assistive technology for the visually impaired. Working with his team, Kurzweil supervised the development of the first charge-coupled device (CCD) flat-bed scanner, which organized signals from groups of photoelectric light sensors and improved the quality and speed of text-to-speech synthesis, incorporating all of these features into the Kurzweil Reading Machine, announced in 1976.

A discussion with musician Stevie Wonder, who was the first individual to purchase a Kurzweil Reading Machine, reignited Kurzweil's interest in using computers for music. In this case, Kurzweil responded to Wonder's interest in using keyboard synthesizers to imitate natural instruments more realistically. In 1982, Kurzweil founded Kurzweil Music Systems, with Wonder as the music adviser. After two years of research and development, the K250 (Kurzweil 250) was released. It was one of the first electronic synthesizers to successfully emulate an acoustic grand piano and other instruments.

During the same period, Kurzweil turned his attention to the development of speech-recognition software. In 1982, he founded another company, Kurzweil Applied Intelligence, to focus on this area. He took advantage of advances in computer memory and architecture to drastically increase the vocabulary of his system, competing with earlier products developed by researchers from Carnegie Mellon University. Realizing that specialized fields such as medicine make use of their own extensive vocabularies, Kurzweil developed systems such as Kurzweil VoiceMED (now Kurzweil Clinical Reporter) so that physicians and other medical professionals could dictate prescriptions, reports, and other kinds of information quickly and less expensively. Further specialization allowed variants of the system to be customized for various branches of medicine.

Ray Kurzweil with speech-recognition technology developed by his company. (Time & Life Pictures/Getty Images)

In the 1990's, Kurzweil started additional ventures, including the Medical Learning Company, which develops computer simulations of the human body for medical training, FatKat financial investment software (1999), and several Web sites, including KurzweilAI.net, promoting discussion and shared research, and KurzweilCyberArt.com, which highlighted machine-generated paintings and poetry. After being diagnosed with type II diabetes, Kurzweil cured himself through diet and nutrition, adding this success to his long list of research topics. Kurzweil also became a prolific author, starting with *The Age of Intelligent Machines* (1990), *The Ten Percent Solution for a Healthy Life* (1993), *The Age of Spiritual Machines* (1998), *Fantastic Voyage: Live Long Enough to Live Forever* (2004; with Terry Grossman, M.D.), and *The Singularity Is Near* (2005). The topics of these books are wide-ranging, but they are unified by an optimistic view of humanity's future.

Kurzweil has been awarded fourteen honorary doctorates and numerous prizes and awards, including Carnegie Mellon University's Dickson Prize (1994), the National Medal of Technology (1999), the Lemelson-MIT Prize (2001), and many others. In 2002, he was inducted into the National Inventors Hall of Fame. He has continued his research and development projects but is also in great demand as a lecturer and inspirational public speaker. *Transcendent Man*, a feature-length documentary film about Kurzweil's life and ideas, was released in 2009.

IMPACT

Even without counting Kurzweil's influence as an author, humanist, and entrepreneur, his many inventions in assistive technology, medicine, word processing, finance, music, and other fields have expanded and extended intellectual, professional, and artistic horizons for millions of people. Over the course of his career, the rapid rise in the availability and power of computers has made it possible to greatly accelerate and miniaturize Kurzweil's earliest inventions, supporting his observations about trends in technology. Some of Kurzweil's inventions and businesses have continued under other companies, which maintain, refine, and market them. His omnifont OCR was purchased by Xerox in 1980 and is now known as Xerox TextBridge. His electronic musical instrument business was sold in 1990 to a Korean piano company, Young Chang, and is now the Kurzweil Music Systems division of Hyundai. The speech-recognition software developed by Kurzweil Applied Intelligence was sold to become the dictation division of Lernout and Hauspie in 1997.

Although not everyone agrees with his utopian vision of a technological singularity (defined by several authors as the point at which machines become more intelligent than people and at which human history as it is known will cease to exist), he continues to stimulate discussion about the fundamental nature of intelligence and its machine-based counterparts, and technology's expanding impact on human culture.

—*John E. Myers*

THE KURZWEIL READING MACHINE

The Kurzweil Reading Machine, the first print-to-speech reading machine for the blind, has provided unprecedented levels of independence to thousands of blind and visually impaired people throughout the world. As they worked on the invention, Ray Kurzweil and his team were enthusiastically supported by the National Federation of the Blind and its leader, Dr. Kenneth Jernigan, who helped them secure development grants. Completed in 1976, the reading machine is actually a combination of Kurzweil's earlier inventions, the first omnifont optical character recognition (OCR) program and the charge-coupled device (CCD) flat-bed scanner, with his refinement of text-to-speech synthesis. The synergy of these three innovations working together to make an even more powerful tool is in itself a perfect example of the inventor's own law of accelerating returns. A page of printed text is scanned, sent to the OCR program, and then read aloud by the speech synthesizer.

On January 13, 1976, Kurzweil and the National Federation of the Blind jointly announced the invention, and the major news networks covered the story. Walter Cronkite used the machine to deliver his closing words on the *CBS Evening News*. Soon after that, Kurzweil demonstrated it on the *Today* show. This attracted the interest of the popular musician Stevie Wonder, who purchased one of the machines for his own use. He loved the device and became Kurzweil's good friend. Their friendship led to further collaborations in music technology.

The Kurzweil Reading Machine, installed in libraries worldwide as well as in homes and offices for personal use, has undergone continued development since its introduction. Over time, the physical footprint of the hardware has gotten smaller. In 2005, the first pocket-size print-to-speech reading machine for the blind was introduced: the Kurzweil-National Federation of the Blind Reader (K-NFB). Developed as a joint venture between Kurzweil Technologies and the National Federation of the Blind, the software can be operated on a full-featured cell phone. With this handheld device, which can provide continuous feedback so that the user can orient its camera for the proper angle, someone who is visually impaired is able to read almost any text that he or she might encounter without needing to carry it to a special location for scanning and processing.

FURTHER READING

Brown, David. *Inventing Modern America: From the Microwave to the Mouse*. Cambridge, Mass.: MIT Press, 2002. Includes a chapter on Kurzweil's invention of the optical reading machine for the blind in 1976. Illustrations, bibliography, and index.

Jahoda, Gerald, and Elizabeth A. Johnson. "The Use of the Kurzweil Reading Machine in Academic Libraries." *Journal of Academic Librarianship* 13, no. 2 (May, 1987): 99-103. Results of a study using a survey of fifty academic libraries using the invention. Includes original questionnaire.

Jurafsky, Daniel, and James Martin. *Speech and Language Processing: An Introduction to Natural Language Processing, Computational Linguistics and Speech Recognition*. Upper Saddle River, N.J.: Prentice Hall, 2000. Comprehensive textbook, organized into four main sections: Words, Syntax, Semantics, Pragmatics. Math formulas, diagrams, charts, tables.

Kurzweil, Ray. *The Singularity Is Near: When Humans Transcend Biology*. New York: Viking Press, 2005. A view of the future based on analysis and projections of trends, making use of Kurzweil's theories on the acceleration of technology as well as his identification of the human brain with massively parallel processors. Notes, index.

Kurzweil, Ray, and Terry Grossman. *Fantastic Voyage:*

Live Long Enough to Live Forever. Emmaus, Pa.: Rodale Press, 2004. Organized into chapters with specific ways to avoid illness and physical degeneration. The basic assumption is that as technology advances, every year that life can be extended (including extensions by methods currently available such as nutrition) will eventually equate to much more than one year of progress in life extension at the current rate, eventually leading toward functional immortality. Bibliography, index.

Weinschenk, Susan, and Dean Barker. *Designing Effective Speech Interfaces*. New York: Wiley, 2000. Focuses on steps to take in project design and human factors rather than on engineering and mathematics. Tables, glossary, bibliography, Web sources, index.

See also: Patricia Bath; Louis Braille; Philip Emeagwali; Federico Faggin; Hugh Le Caine; Robert Moog; Jacob Rabinow; Claude Elwood Shannon.

STEPHANIE KWOLEK

American chemist

During her years as a DuPont chemist, Kwolek discovered a new branch of synthetic materials: liquid crystalline polymers. Her innovations in polymer science led to the development of the high-performance fiber Kevlar.

Born: July 31, 1923; New Kensington, Pennsylvania
Also known as: Stephanie Louise Kwolek (full name)
Primary field: Chemistry
Primary invention: Kevlar

EARLY LIFE

Stephanie Louise Kwolek (KWAW-lehk) was born in New Kensington, Pennsylvania, in 1923. Her parents, John and Nellie (Zajdel) Kwolek, immigrated to America from Poland when they were in their teens. John Kwolek was a foundry worker and amateur naturalist, and he encouraged his daughter to take a scientific interest in her surroundings. Together, the two explored the woods near their home, observing wildlife and collecting seeds, leaves, and flowers. At home, they studied and cataloged their botanical samples. The young Stephanie also enjoyed designing fashions, and she spent many hours sketching and making clothes for her dolls.

John Kwolek died when his daughter was ten years old, leaving his wife to raise Stephanie and her younger brother alone. To support the family, Nellie Kwolek found a job as a kitchenware assembly-line worker at the local Alcoa plant. As Stephanie grew older, she developed an interest in becoming an educator. She took to teaching math, reading, and writing to the other children in her neighborhood. She showed an affinity for the sciences during her school years, and by the time she headed for college in 1942 she had plans to become a doctor or a chemist.

Kwolek attended Margaret Morrison Carnegie College in Pittsburgh, the women's college of the Carnegie Institute of Technology (now the coed Carnegie Mellon University). During her studies there, which were funded by scholarships, she realized that she would be unable to afford medical school. She decided that after graduation she would seek work as a chemist to earn money for later graduate studies in medicine. With that goal in mind, she majored in chemistry and minored in biology. Kwolek received her bachelor's degree in 1946.

LIFE'S WORK

Job opportunities in scientific and technical fields had opened up for women during World War II, and Kwolek interviewed with several research companies. Ultimately, she found a position with E. I. du Pont de Nemours and Company, which hired her as a research chemist for its textile fibers laboratory in Buffalo, New York.

Kwolek thrived in the intellectually engaging environment at DuPont. She and her colleagues were working to create new synthetic polymers (long-chained molecules), and DuPont's research facility was the site of pioneering work. She and her coworkers helped one another and learned from each other. DuPont maintained a top-notch research library and invited professors to come discuss their latest research with laboratory staff. Kwolek so enjoyed her work as a research chemist that she decided not to pursue a career in medicine after all. She would remain with DuPont for the next forty years.

Although DuPont employed Kwolek and other women in a traditionally male field, women in postwar America generally found it hard to build and advance careers or to gain recognition in scientific or technical areas. Many of Kwolek's female coworkers left the company after a few years to become homemakers and mothers; others,

A DuPont executive holds a spool of Kevlar, best known for its use in body armor. (AP/Wide World Photos)

frustrated with limited opportunities for advancement, moved on to careers in teaching. Kwolek, who never married, stuck with her job despite unequal treatment. She received her first promotion after she had worked for DuPont for fifteen years.

In 1950, Kwolek was one of several employees at the Buffalo plant who earned a transfer to DuPont's newly opened Pioneering Research Laboratory in Wilmington, Delaware. There, in the Textile Fibers Department, the research team created and tested hundreds of thousands of new synthetic polymers.

Kwolek's early work at DuPont focused on discovering polymers that would dissolve at low heat so that they could be spun into fibers at room temperature. Her advances in low-temperature processes for preparing condensation polymers laid the groundwork for the discovery of several of DuPont's commercial products, including Lycra spandex, the flame-resistant material Nomex, and the multipurpose film Kapton.

In 1964, in the face of predicted gasoline shortages, DuPont set a goal to find a strong, lightweight, high-performance fiber for use in automobile tires. Replacing the heavy steel reinforcement in tires with a lightweight, textile-type fiber would improve gas mileage. Other chemists seemed uninterested in piloting the task, so Kwolek took on the challenge. The polymer needed to be stable at high temperatures and resistant to acids and bases. One of her experiments yielded surprising results. After synthesizing two aromatic polymers that subsequently refused to melt, Kwolek decided to use a solvent to dissolve them into liquid. However, when she mixed one of the polymers with the solvent, she did not get the clear, syrupy solution she expected from a flexible polymer chain. Instead, the resulting fluid was thin—almost like water—and hazy. She tried filtering the solution, but it retained its milky appearance.

Kwolek submitted the solution to a coworker who operated the lab's spinneret, a device used to spin polymer solutions into fiber. He initially refused, convinced that the solution was not cohesive enough to spin and fearful that the cloudy liquid was full of suspended particles that would clog his equipment. When she finally persuaded him to try, the solution spun flawlessly. She submitted the resulting fiber to the physical test lab, which found it to be surprisingly strong and stiff. Heat-treating it, she discovered, intensified its properties. Kwolek resynthesized and retested the new fiber repeatedly before she announced her results.

Kwolek had stumbled upon a new branch of synthetics: liquid crystalline polymers. She had also synthesized something new: a para-aramid fiber. DuPont recognized the commercial potential of the new fibers and set out to create one that was right for commercial production. Lab staff went to work experimenting with other liquid crystalline solutions, thinking up applications for the new fibers and developing new equipment for spinning, testing, and cutting them. After more than half a decade of research and refinement, a commercially viable fiber emerged that was less dense than fiberglass but far stronger than steel. Kwolek applied for a patent for the fiber, which DuPont would dub Kevlar, in 1971. The patent was granted in 1974, and bullet-resistant Kevlar vests went on the market a year later.

Kwolek continued to research polymers at DuPont until her retirement in 1986. She is the holder or coholder of seventeen U.S. patents; these include one for the spinning method that made commercial aramid fibers possible and five for the prototype polymer from which Kevlar was developed.

Since retirement, Kwolek has continued to work part-time as a consultant. She has also lectured, mentored, and participated in education outreach activities to encourage young people in science.

IMPACT

Kwolek revolutionized chemistry with her discovery of liquid crystalline polymers. By laying the technological foundations for Kevlar body armor, she has also saved thousands of lives. However, Kwolek's impact is not limited to her pioneering discoveries. She has dedicated her post-retirement years to mentoring female scientists and encouraging children, particularly girls, to pursue careers in science. She has not only lectured about her life and work but also welcomed curious students into her home and taken phone calls from children needing homework help. Her scientific curiosity, persistence, and determination make her an excellent role model who shows how science can provide opportunities for both intellectual challenges and valuable contributions to society.

Kwolek's work has earned her multiple honorary degrees and several major awards and distinctions. In 1994, she was named a Kilby Laureate for her revolutionary discoveries. In 1995, she was among the first recipients of the U.S. Patent and Trademark Office's newly established American Innovator Award. The following year, President Bill Clinton awarded her the country's highest honor for technological achievement, the National

KEVLAR

Kevlar (polyparaphenylene terephthalamide) is the trade name for a strong, lightweight para-aramid synthetic fiber manufactured by DuPont. Weight for weight, it is five times stronger than steel, yet it is 43 percent less dense than fiberglass. It is nonconductive, it does not rust, and it resists wear, fatigue, corrosion, and heat. Its unique properties make it ideal for a wide range of applications. In a liquid crystal solution, such as the one from which Kevlar is made, the molecules are in an orderly, tightly packed formation. When such a solution passes through a spinneret, the aligned molecules remain in parallel as the solvent is forced out. The tightly packed, parallel, rigid molecules create an extremely strong fiber.

Kevlar is best known as the material used in bullet- and knife-resistant protective gear. When a bullet strikes a fabric woven from Kevlar, the fibers at the point of impact stretch instead of breaking and thereby dissipate the energy of impact. Kevlar vests have protected thousands of police officers from gunshot and knife wounds. Kevlar helmets have been standard issue for American combat soldiers since the early 1990's. In war zones, Kevlar body armor protects military personnel and civilians alike.

The U.S. space program employs Kevlar for various uses on the space shuttle and the International Space Station. Closer to Earth, Kevlar is used in containment rings for jet engines. If a piece of an aircraft turbine were to break off in flight, shrapnel would be traveling fast enough to slice through the engine and beyond. Kevlar shielding ensures that metal shards are contained or deflected.

Kevlar cable is used in suspension bridges and in the moorings that anchor oil-drilling platforms to the ocean floor. In the automotive industry, uses for Kevlar include radial tires and transmission belts. The material's durability and heat resistance have made it an ideal replacement for asbestos in brake pads. The high-performance material is also used in sports and recreation equipment such as skis, tennis rackets, hockey sticks, bicycle tires, fishing line, and racing sails. Canoes and kayaks made with Kevlar are strong and lightweight, like carbon-fiber models, but they have more give. Kevlar boots provide hunters with protection from snakebites.

Medal of Technology. In 1997, she became the second woman to receive the American Chemical Society's Perkin Medal for her innovative work in applied chemistry. She was the 1999 recipient of the Lemelson-MIT Lifetime Achievement Award. She is an inductee of the National Inventors Hall of Fame (1995), the Women in Technology International Hall of Fame (1996), and the National Women's Hall of Fame (2003).

—*Karen N. Kähler*

FURTHER READING

Brown, David E. *Inventing Modern America: From the Microwave to the Mouse*. Cambridge, Mass.: MIT Press, 2002. The chapter devoted to Kwolek presents an overview of her career at DuPont. A sidebar describes Kevlar's use in sporting equipment. Photographs, list of sources and further reading, index.

Macdonald, Anne L. *Feminine Ingenuity: How Women Inventors Changed America*. New York: Ballantine Books, 1992. The author interviews Kwolek in conjunction with the U.S. Patent and Trademark Office's 1990 special exhibit, "A Woman's Place Is in the Patent Office," at which Kwolek was a featured speaker. Bibliography, patents list, notes, index.

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See also: Wallace Hume Carothers; William David Coolidge; Roy J. Plunkett; Toyoichi Tanaka; Otto Wichterle.

RENÉ-THÉOPHILE-HYACINTHE LAËNNEC

French physician

Laënnec revolutionized medicine through his research in pathological anatomy and his work in clinical diagnosis. His invention of the stethoscope made possible accurate diagnosis of chest and heart problems.

Born: February 17, 1781; Quimper, France
Died: August 13, 1826; Kerlouanec, France
Primary field: Medicine and medical technology
Primary invention: Stethoscope

EARLY LIFE

René-Théophile-Hyacinthe Laënnec (ruh-NAY tay-aw-FEEL yah-SAHNT lay-NEHK) was born in Quimper, France, on February 17, 1781. When he was five years old, his mother died of tuberculosis. His father did not feel that he could take care of the boy properly, so René was sent to live with his great uncle the Abbé Laënnec. He was not a healthy child; he suffered from pyrexia and asthma and spent much of his time playing the flute and writing poetry. He also learned Greek and Latin and studied the classics.

The majority of the Laënnec family were lawyers, and many held positions in the parliament of Brittany. However, René's uncle Dr. Guillaume François Laënnec was dean of the medical school at the University of Nantes. René's interest was in medicine, not law, and when he was twelve years old he went to Nantes, where his uncle encouraged him to pursue a medical career. In 1795, when he was only fourteen years old, René was already working at the Hôtel-Dieu in Nantes, assisting with the care of patients, and there he began his medical education with his uncle. At the age of eighteen, René was serving as a third-class surgeon in the Military Hospital of Nantes. A short time later, he was at the Hospice de la Fraternité and then a surgeon at the Hôtel-Dieu. This was an excellent opportunity for the young man to observe a large variety of patient treatment and surgery.

In 1801, Laënnec went to Paris, where he studied medicine at the École Pratique and at the Hôpital de la Charité. He attended lectures given by the most talented physicians of the day: He learned dissection and was introduced to macroscopic pathology in the laboratories of Guillaume Dupuytren; studied heart and pulmonary conditions with Jean-Nicolas Corvisart, Napoleon Bonaparte's doctor; listened to Philippe Pinel, the founder of modern psychiatry, explain his theories of mental illness as a disease; and was a student of anatomy and physiology with Marie François Xavier Bichat, the father of the science of anatomy. Laënnec was especially talented as a diagnostician and as a pathologist. Soon, he started to do research on his own and to publish his findings in medical reviews.

In 1802, at the age of twenty-two, he obtained first place in the Concours Général de Médecine et de Chirurgie (general medicine and surgery exam). That year, he published a number of papers on various medical subjects and served as editor of the *Journal de Médecine*. While preparing his thesis, he gave private classes on pathological anatomy. In June, 1804, he defended his thesis and graduated.

LIFE'S WORK

Laënnec's career in medicine combined the fields of research scientist, practicing physician, and medical jour-

René-Théophile-Hyacinthe Laënnec. (Getty Images)

THE STETHOSCOPE

In 1816, a very obese young woman suffering from general symptoms of heart disease consulted René-Théophile-Hyacinthe Laënnec for treatment. Laënnec was perplexed about how to perform a clinical examination on her. Although he often used the technique of percussion, he rejected it in this case, as her extreme fatness would render it ineffective. Given her age and sex, direct auscultation of her heart with his ear placed against her chest was in his opinion inappropriate. While Laënnec happened to be watching some children playing, he noticed that they were holding a piece of wood to their ears and scratching on the other end with a pin. This observation inspired him to roll up a cylinder of paper that he tied with a string and to use it to examine her. He placed one end of the cylinder over her heart and the other end to his ear. The results were excellent; he could clearly hear the sounds made by her heart.

Pleased with the excellent results, Laënnec proceeded to construct a more durable instrument. He used a hollow wooden cylinder that measured 25 by 2.5 centimeters. Later, he improved upon his instrument by adding detachable parts and using brass rings. He created a detachable chestpiece and modified the stethoscope so that the earpiece could be unscrewed.

Wooden stethoscopes remained in use in the middle of the nineteenth century. The development of rubber tubing permitted the construction of different kinds of stethoscopes. In 1850, the modern binaural stethoscope with rubber tubes leading to both ears was developed. Types of stethoscopes include acoustic, electronic, and differential stethoscopes.

nalist. After graduating, he became an associate of the Société de l'École de Médecine and published a considerable number of articles, many of which dealt with pathological anatomy. However, his article on melanoma published in 1806 resulted in a rupture with Dupuytren, who insisted that Laënnec had failed to give him adequate credit for his work in the field. This quarrel, coupled with family problems, his uncle's death from tuberculosis, and financial difficulties, caused Laënnec a number of health problems, and he was forced to return to his native Brittany to recuperate.

Once his health was restored, Laënnec returned to Paris, became an editor-shareholder of the *Journal de Médecine*, and once again established a private practice. In 1808, he founded the Athénée Médical. He received an appointment as personal physician to Cardinal Joseph Fesch, Napoleon's uncle, and also published a number of articles on pathological anatomy. In 1810, Georges Cuvier, the founder of pathological anatomy, praised Laënnec as one of the very best in that field.

During the war years of 1812 and 1813, Laënnec was at the Salpétrière Hospital taking charge of the wounded Breton soldiers. He also taught medical pathology at the Hôpital Necker. During this period after his return to Paris, Laënnec was disappointed that he had not been offered a senior position as a physician in a Paris hospital. The offer finally came in 1816 from the Hôpital Necker. Laënnec immediately accepted and enjoyed a vast celebrity as a doctor. It was while he was at Hôpital Necker that he would make his most significant medical contribution, the stethoscope. In 1819, an obese young woman with symptoms of heart disease became his patient. Due to the impossibility of using percussion and the impropriety of placing his ear to her chest, he searched for another method and invented the stethoscope.

Shortly thereafter, Laënnec received a number of honors. In July, 1822, he was appointed chair and professor of medicine at the Collège de France. In January, 1823, he was accepted as a full member of the French Academy of Medicine. He also received an appointment as a professor at the medical clinic at the Hôpital de la Charité. In 1824, he was awarded the Legion of Honor.

Throughout his life, Laënnec was a devout Catholic and a kind and generous individual. He counted among his patients many famous people such as the author François-René de Chateaubriand, but he also treated many poor patients. Laënnec did not marry until 1824, just shortly before his death from tuberculosis. In May, 1826, suffering from deteriorating health, he left Paris and returned to Brittany, hoping to restore himself to better health. He continued to deny that his illness was tuberculosis until he asked his nephew Mériadec to listen to his chest with a stethoscope and describe his findings. What Mériadec reported left no doubt in Laënnec's mind that he was dying from tuberculosis. He willed all of his scientific papers, his watch, and his ring to this nephew. He also left him his stethoscope. Laënnec truly realized the importance and value of his invention and described it as the best item he was leaving to Mériadec. On August 13, 1826, he died in Kerlouanec, France.

IMPACT

Laënnec had a most significant impact on medicine both as a researcher and as a practicing physician. Influenced by the teachings of Corvisart, who had reintroduced the usefulness of chest percussion first used by Leopold

Auenbrugger, Laënnec further explored this method and published the results of his work, which became the basis for diagnosing chest disease.

His greatest contribution to diagnosis of chest illness was his invention of the stethoscope, which made accurate diagnosis possible in cases that otherwise remained unclear. In 1818, he appeared before the Academy of Science in Paris with his findings and research on the stethoscope. In 1819, he published his two-volume work on the stethoscope and chest disease, *De l'auscultation médiate* (*On Mediate Auscultation*, 1821). Laënnec's treatise brought a large number of physicians to Paris to see the stethoscope and to consult with him about its use. A revised version of the book, which correlated the sounds heard with the stethoscope with the lesion found at autopsy, was published in 1826.

Laënnec gave the liver disease known as cirrhosis its name. He also made important discoveries about melanoma and distinguished its lesions from those of tuberculosis. He advanced the diagnosis of heart problems through his research. Using his stethoscope, he discovered and described two distinct heart sounds. As a result of his research and active practice as a physician, Laënnec advanced both the knowledge and the methods of diagnosis available to physicians. He perfected the art of clinical diagnosis, which became one of the most valuable tools for the physician in the treatment of diseases, especially those of the chest. His invention of the stethoscope enabled physicians to distinguish and diagnose various chest diseases.

—*Shawncey Webb*

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See also: Marie Anne Victoire Boivin; Raymond Damadian; Willem Einthoven; Helen M. Free; Wilson Greatbatch.

EDWIN HERBERT LAND

American physicist

The two most important achievements in Land's career were the development of effective and inexpensive sheet polarizers in the 1930's and the invention of instant photography in sepia (1947), black and white (1950), and color (1963).

Born: May 7, 1909; Bridgeport, Connecticut
Died: March 1, 1991; Cambridge, Massachusetts
Also known as: Din Land
Primary fields: Chemistry; optics; photography; physics
Primary inventions: Instant photography; sheet polarizers

EARLY LIFE

Edwin Herbert Land was a very private person who devoted himself to his work, so not much is known about his private life or early history. He was the son of an immigrant to the United States from Odessa, Russia, who settled in Bridgeport, Connecticut, and ran a successful scrap metal business. Land's father, Harry, married Matie Goldfaden, and their first child was a girl named Helen. When Helen's little brother was born, she could not pronounce "Edwin" correctly at first, and her approximation, "Din," became his lifelong nickname.

As a child, Edwin was fascinated by kaleidoscopes and magic-lantern shows. He discovered the textbook *Physical Optics* (1905) by Robert W. Wood and read it, he claimed, as if it were the Bible. When the thirteen-year-old Edwin was at summer camp, a counselor used a piece of Iceland spar (crystallized calcium carbonate) to remove the glare from a tabletop, impressing the boy. Again, later that summer, he was in a car that narrowly missed hitting a farm wagon because of poor visibility from headlight glare. Removing glare from headlights became the primary motivation in his research to develop the sheet polarizer, a device for filtering the type and amount of light to pass through.

Land entered Harvard College in 1926 but was soon bored and dropped out. After a brief stay in Chicago to indulge a bohemian fantasy of the writer's life, he relocated to New York City and began independent research into light polarization. He succeeded in 1929 and filed for the first of his many patents. In the fall of that year, Land returned to Harvard to resume his studies and married Terre Maislen, who was to be the mother of his two daughters, Jennifer and Valerie.

Edwin Herbert Land, who founded Polaroid in 1937, demonstrates instant photography. (AP/Wide World Photos)

LIFE'S WORK

The first sheet polarizer was created by electromagnetically aligning tiny crystals of herapathite (iodoquinine sulfate) in solution, then dipping a celluloid strip in the concoction in order to apply a coat of oriented platelets. An improved method involved much tinier crystals that were oriented on the celluloid or plastic strip by radical extension or stretching.

Land began negotiating with General Motors (GM) and other automobile companies in 1931 about instituting a universal system for headlights and windshields (or goggles) to control glare while driving. These discussions continued until the late

1940's but never bore fruit. One probable reason for this was the need to introduce such a system all at once, eliminating the competitive advantage for any one automobile company. Other safety innovations such as dimmers for headlights, improved brakes, seat belts, and airbags could be introduced piecemeal and provide marketing advantages. Polarized headlights would also have to be some fifty times brighter than the ordinary kind and therefore would drain a car's battery that much more.

Other commercial opportunities did develop for Land's invention, however. He began providing Kodak with polarizing filters for cameras marketed as Polascreens, and he signed contracts with American Optical to make polarizing lenses for sunglasses. Metro-Goldwyn-Mayer (MGM) demonstrated three-dimensional (3-D) movies at the New York World's Fair of 1939-1940, and they were viewed with Land's dark, polarizing plastic glasses, which returned briefly for the 3-D movie craze of the early 1950's.

Land founded the Polaroid Corporation in 1937, and he was given total control for the first ten years. Very soon, however, World War II started, and Land put his company at the service of the war effort. Polaroid developed a system for 3-D reconnaissance photography called the Vectrograph for the U.S. military. The company worked on heat-sensitive guidance systems for bombs and proximity fuses that would detonate explosives at a set distance from targets. Polaroid also made machine-gun trainers with simulated tracer bullets, plastic lenses, nonpolarizing filters, and different kinds of gun sights and goggles. Though Polaroid's volume of business increased dramatically, company profits remained about the same during this period.

At the end of 1943, Land found inspiration for the achievement for which he is best known. He took a photo of his daughter Jennifer while they were on vacation in New Mexico, and she asked why she had to wait so long to see the result. The idea of instant photography was thus implanted in the fertile mind of Land. His first system was put on the market in 1948. Land continued to perfect his invention, finally bringing out the classic SX-70 in 1972.

During the Cold War, Land was asked to serve on a number of advisory committees to help the U.S. government take best advantage of the country's scientific potential. He participated in Project Charles, which reported to the president in August of 1951, and then worked on Project Beacon Hill. He was a member of President Dwight D. Eisenhower's Science Advisory Committee, created in 1954, and he served on this committee until it was abolished by President Richard M. Nixon. Land was also involved in developing photographic systems for reconnaissance planes and satellites

INSTANT PHOTOGRAPHY

In 1943, while vacationing in New Mexico with his wife, Terre, and daughter, Jennifer, Edwin Herbert Land took a photograph of his daughter, who asked why the picture did not develop immediately. Her question set in motion a momentous chain of events. Land claimed that the essentials of the instant photography system developed in his mind that very day. All the chemical complexities of bringing a photograph to life in a darkroom were to be shrunk to the size of a normal camera and performed in a few seconds.

With Land's process, tiny pods protected the chemical reagents from air until the critical moment. Then, after exposure, small rollers would rupture the pods and press the latent image of the negative and the positive print together for instant, simultaneous development. This new approach was referred to as diffusion transfer. Finally, the development process had to be stabilized and the print dried in a matter of seconds to produce the immediately viewable photo.

The process for instant development of color photos was even more complex, and Land worked closely with Howard Rogers at Polaroid for this purpose. Rogers developed new molecules for the primary colors, each acting both as a developer and image dye. These molecules made the chemical couplers used in Kodachrome and in other color systems unnecessary, and they made possible the required compression of the process. Polacolor was introduced in Florida in January of 1963, and it was an immediate success among vacationers. An important marketing advantage was that this film worked in existing Polaroid cameras.

The ultimate camera for instant color photography, however, was not brought out until 1972. The SX-70 was new in appearance, flash system, viewing-system electronics, and film structure. The design of the SX-70 was so ambitious and sophisticated, however, that problems arose in the manufacturing process after it was introduced. Polaroid had trouble finding subcontractors with the requisite expertise and had to assume more of a manufacturing role than could easily be accomplished. The SX-70 did finally make a profit, but not as much as its cheaper and simpler variations, such as the OneStep. By the end of the century, both would become defunct with the rise of digital photography.

such as the U-2, the Blackbird, and the Corona. He also helped develop a small camera used by Neil Armstrong on the first Moon landing of Apollo 11 in 1969.

Land was a successful businessman who made a fortune in his life and prided himself on fulfilling practical needs of society with his inventions, but he was also interested in pure science. His work in photography led him to question certain assumptions about the nature of light and the phenomenon of color. Land was intrigued that he could not establish a clear connection between the wavelength of light reflecting off objects into the eye of the beholder and the color perceived. His retinex theory eventually showed that there are certain specialized cells in the retina that are sensitive to certain colors: There are other cells in this area and in the cerebral cortex that criticize and compare these basic reactions. Color constancy is now understood as an extremely complex, relative process involving subtle comparisons of the focal area with the background of any given scene. Land began his experiments in this area in 1955, but his ideas were not accepted by neurophysiologists until the early 1980's.

Polaroid Corporation and Land had a long and complicated relationship with the dominant player in the photography business, the Eastman Kodak Company. When he was just starting out, Land supplied Kodak with products and licensed the company to use some of his patents. Later, the companies collaborated, as Polaroid sometimes availed itself of Kodak facilities and its manufacturing capacity. Finally, when Kodak decided to enter the instant photography field, the two became bitter rivals. Polaroid took Kodak to court in 1976 for patent infringement of Polaroid's instant photography products and won the case. Kodak was ordered to stop making those products in 1986 and had to pay Polaroid $900,000 in damages in 1991.

Toward the end of his career, Land seemed to lose a bit of his flexibility. In the final development phase of the SX-70 camera model, he pushed for his own ideas regarding the viewfinder and other aspects of the camera in a way that alienated many people. He was forced to step down as president of the company in 1975, and William J. McCune took over that post. Land's pursuit of instant movies proved to be his one major business mistake. Polavision was a technological marvel, but it was developed with little regard for the bottom line and without appreciation of the advantages of videotape, which became the dominant technology in the field.

After the failure of Polaroid's instant movies in the marketplace, Land was forced to give up his position as chief executive officer in 1980. He resigned as chairman and member of the board in 1982 and had liquidated all of his Polaroid holdings by 1985. He devoted the rest of his life to the research foundation he endowed, called the Rowland Institute.

IMPACT

Land was a major force in the science of optics. During his lifetime, he held 535 U.S. patents in this and related fields, more patents than anyone except Thomas Alva Edison. Land's genius made possible the creation of two major industries to manufacture and market sheet polarizers and instant photography. Polaroid Corporation dominated both industries for almost half a century under Land's direction.

The Franklin Institute awarded Land the Cresson Medal in 1937. He received the Presidential Medal of Freedom in 1963 and the National Medal of Science in 1968. He was inducted into the National Inventors Hall of Fame in 1977. Land was honored as a foreign member of the Royal Society of London in 1986.

The Rowland Institute for Science, which Land endowed in 1980, merged with Harvard University in 2002 and is now called the Rowland Institute at Harvard. It specializes in interdisciplinary research primarily in chemistry, physics, and biology. The research seminar for Harvard College freshmen is located there, embodying Land's idea of involving students in actual research early in their college education.

—*Steven Lehman*

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troduction to the history of the art and science of photography from the first camera obscura to contemporary digital technology.

See also: Louis Jacques Daguerre; George Eastman; Leopold Godowsky, Jr.; Leopold Mannes; Nicéphore Niépce.

Samuel Pierpont Langley

American physicist and astronomer

Langley designed and built the first powered aircraft that could remain aloft in sustained flight.

Born: August 22, 1834; Roxbury, Massachusetts
Died: February 27, 1906; Aiken, South Carolina
Primary fields: Aeronautics and aerospace technology; astronomy
Primary invention: Aerodromes

Early Life

Samuel Pierpont Langley was born in the Boston suburb of Roxbury, Massachusetts, the son of Samuel and May Williams Langley, part of a distinguished old New England family. The elder Langley was a successful Boston businessman with wide interests outside his business, including an active interest in astronomy. When young Samuel was a boy, he was intrigued by his father's telescope and, together with his brother John, used it to explore the heavens. As teenagers, the boys became well grounded in both astronomy and instrument making.

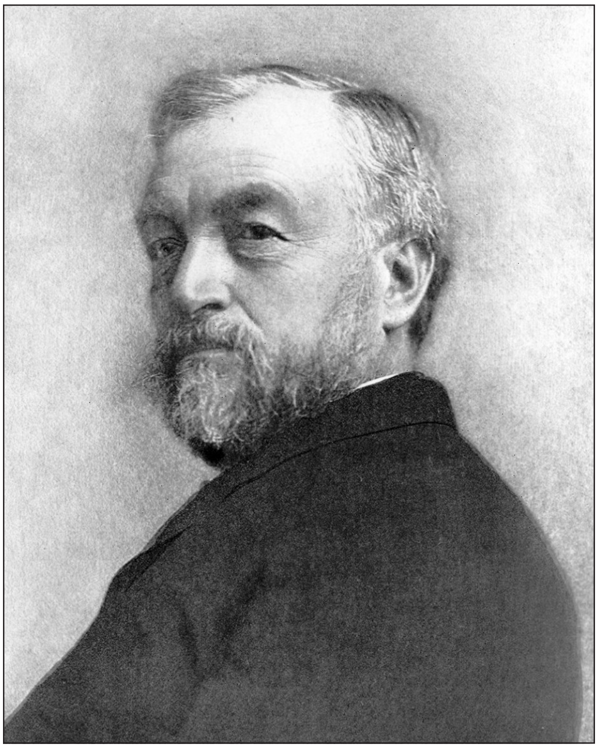
Samuel was sent to Boston Latin School and Boston High School, graduating when he was seventeen. While in school, he excelled in science and math and developed skills in mechanical and engineering fundamentals. Still interested in astronomy, he knew that he would be unlikely to have a career in that field, as there were very few opportunities for employment in what was considered a useless, though interesting, activity.

Although Langley did not attend college, his quick intelligence and skill with mathematics and mechanics led to employment as a civil engineer and architect. His early employment was in Boston, but he eventually moved west to take up positions in Chicago and St. Louis, Missouri. These were important learning experiences, as he became skilled in mechanical drawing and he developed a talent for the design of instruments as well as buildings. However, Langley gave up a career in architecture in 1864 and returned to his boyhood home in Roxbury. He and his brother John were both uncertain about their future but had retained a strong interest in astronomy. Encouraged by a newly developed method of building a reflecting telescope using a glass mirror with a silvered surface, the brothers worked at perfecting the technique, eventually producing an instrument of high quality.

In 1865, the brothers toured Europe, visiting the usual grand tour cities and cultural centers. When they returned to Roxbury, Samuel was thirty-one years old and still seeking a career. Having heard about the expansion of the Harvard College Observatory, located in nearby Cambridge, Massachusetts, Samuel applied to the director, Joseph Whitlock, for a position and was hired as observatory assistant.

Life's Work

Although the world remembers Langley for his experiments with powered flying machines, his career was



Samuel Pierpont Langley. (Library of Congress) mainly in the field of astronomy. Beginning with the position at the Harvard Observatory, he moved with almost unbelievable speed up the ladder of professional science. After only a year at Cambridge, he moved to Annapolis, Maryland, where he became professor of mathematics at the U.S. Naval Academy. His duties while at Annapolis were chiefly concerned with the academy's small observatory.

Further rapid progress in the academic world occurred in 1867, when he was appointed director of the Allegheny Observatory and professor of astronomy of the University of Western Pennsylvania (now the University of Pittsburgh). This observatory had been deeded to the university by a group of amateur astronomers who had lost interest in its use and upkeep. As a professor of astronomy and physics, Langley was expected to teach appropriate courses and care for the observatory as a teaching facility.

The young professor wanted to make the observatory into an active research center, but there were no funds for this, so he sought a method of earning the observatory's support. The instruments could provide one important service: determining the correct time. At that time, there was no standard source of time; each city determined its own time by whatever means it could. Langley arranged with the Pennsylvania Railroad to provide accurate time twice a day to its hundreds of telegraph offices. Soon, others for whom accurate time was important sought this service, too, and the observatory was at last financially supported.

Langley's chief astronomical interest in Pittsburgh was the Sun, and he was particularly concerned with determining the solar constant, which is the rate of solar energy release as measured from the Earth. He experimented with methods of detecting infrared light, for which he developed infrared-sensitive measuring instruments. This work led to his invention of the bolometer, a highly sensitive device used to measure temperatures of radiant bodies like the Sun at various wavelengths.

Another interest that Langley developed in Pittsburgh had little to do with his position as an astronomer. It is said that he was inspired by a talk on avian flight that he heard at a meeting of the American Association for the Advancement of Science. He began to look into how birds can sometimes sustain flight without moving their wings. Langley realized that the secret of avian gliding might be the key to the development of a flying machine. To solve the secret of flight, he experimented with a rotating arm device that allowed him to measure the properties of wings of various shapes moving through air at various velocities. The result was an array of experimental results that formed an important cornerstone in the foundation of the field of aeronautics. These results were published in his book *Experiments in Aerodynamics* (1891).

Langley's reputation as a dynamic and resourceful scientist resulted in his being chosen to be the secre-

AERODROMES

Samuel Pierpoint Langley's unmanned aerodromes were pioneering aircraft in the development of flight. After having decided in 1897 to withdraw from the enterprise of building a craft that could carry a man, Langley had second thoughts almost immediately. War with Spain began in 1898, and President William McKinley persuaded Langley to take up his aeronautics work again so that it might be possible to use manned aircraft in military applications. He agreed to do so and immediately began to construct an aerodrome that would follow the design of Nos. 5 and 6, but that would be large enough to carry the weight of a person. Langley hired a young engineer, Charles Manly, to direct the construction and develop the engine, which would have to be much more powerful than the small steam engines used thus far. This turned out to be very difficult, but by late 1900 Manly had built a gas-powered engine that weighed 124 pounds and delivered 52 horsepower.

After much testing and adjusting, Langley and Manly decided to make a test flight of the new aerodrome from the roof of a houseboat on the Potomac River. On October 7, 1903, with Manly aboard the craft and with the surrounding waters full of the boats of newspaper reporters, the aerodrome was catapulted from its launch vehicle, only to plummet straight down into the river. Afterward, Langley explained that the problem had been a failure of the launching mechanism, not the aerodrome. However, the newsmen, who had been kept waiting for months for this flight, made spectacularly disparaging remarks about the failure.

The damaged craft was quickly rebuilt and again made ready for flight on December 8, 1903. In front of many onlookers and members of the press, Manly again boarded the craft, which was launched over the icy Potomac. This time, something caused part of the tail to drag on the ways, with the result that the aerodrome flew up instead of down, entirely flipping onto its back and falling to the river. Miraculously, Manly was able to free himself from under the ruined craft and come to the surface among the ice floes. Neither he nor Langley attempted to fly the aerodrome again.

tary—that is, the director—of the Smithsonian Institution in 1887. In this post, he continued to carry out solar research, eventually establishing the Smithsonian Astrophysical Observatory, which is now one of the largest astronomical research institutions in the world. His research continued to deal with solar radiation at various wavelengths.

The resources of the Smithsonian Institution also favored continuing research on the physics of flight. Langley used his rotating arm instrument to test various wing designs and even tried it out on actual birds' wings, concluding that a bird, without sensitively controlled muscles to power and to adjust its wings, would not have loft enough to maintain flight. Langley also began experiments with what we would call "model airplanes," powered by rubber bands. Building them with a variety of different designs and wing shapes, Langley flew more than one hundred of these, attaining flights of as much as one hundred feet. These simple experiments showed promise and led to the next stage, the design of a powered flying machine. Langley called these "aerodromes." The first was powered by a small steam engine. Others used carbonic acid gas, compressed air, and, eventually, gasoline engines. The most successful flight was made in 1896 by his Aerodrome No. 6, which flew a distance of forty-eight hundred feet. This was considered to be the first successful flight of a self-propelled machine that kept aloft for a significant amount of time and for a significant distance.

Langley published a review of these experiments in 1897 in which he said that he felt that his task was finished; he had shown that sustained flight by powered flying machines was possible and that others should next try to fly a manned aircraft. However, external events convinced him to carry on, and he eventually made two unsuccessful attempts to fly a manned version of his aerodrome. Langley died in 1906 in Aiken, South Carolina.

IMPACT

Langley's astronomical work was devoted to the new field of astrophysics, and he was one of the principal developers of the application of physics to the understanding of the stars and planets. His exploration of the spectrum of light into the hitherto unknown infrared region made possible an entirely new way to measure the emission of sunlight and starlight. His invention of the bolometer was an important step in the development of infrared astronomy. His devotion to making science available to the public set an important precedent for his colleagues. Although he considered himself primarily an astronomer, Langley is best known for his experiments in aeronautics, which resulted in the first flight by a self-powered heavier-than-air machine.

—*Paul W. Hodge*

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See also: ʿAbbas ibn Firnas; Emile Berliner; George Cayley; Sir Christopher Cockerell; Glenn H. Curtiss; Robert H. Goddard; Bill Lear; Louis-Sébastien Lenormand; Leonardo da Vinci; Edwin Albert Link; Paul B. MacCready; Joseph-Michel and Jacques-Étienne Montgolfier; Hans Joachim Pabst von Ohain; Burt Rutan; Igor Sikorsky; Charles E. Taylor; Andrei Nikolayevich Tupolev; Faust Vrančić; Sir Frank Whittle; Sheila Widnall; Wilbur and Orville Wright; Ferdinand von Zeppelin.

IRVING LANGMUIR

American physical chemist

Langmuir's exploration of surface phenomena and thin films led to important practical applications and a Nobel Prize in Chemistry. He is best known for his contributions to the development of the commercially successful incandescent bulb.

Born: January 31, 1881; Brooklyn, New York
Died: August 16, 1959; Falmouth, Massachusetts
Primary fields: Chemistry; physics
Primary invention: Gas-filled incandescent light bulb

EARLY LIFE

Irving Langmuir (LAYNG-myoor) was the third of four boys born to Charles and Sadie (née Comings) Langmuir. His early education included schools in both New York and Paris. In 1899, he entered the Columbia University School of Mines for its rigorous curriculum in chemistry, physics, and mathematics. He graduated with a degree in metallurgical engineering in 1903.

Like many aspiring chemists at the beginning of the twentieth century, Langmuir went to Germany for graduate study. At the University of Göttingen, he studied with Walther Nernst, winner of the 1920 Nobel Prize in Chemistry. At first, it appeared that Nernst and Langmuir would not be a good fit as a doctoral research team. Langmuir complained that Nernst spent all his time on his own research and ignored him. There is evidence that Nernst did not see much potential in the American. Nernst was deeply involved in the study of thermodynamics at that time. His work in this field, which combines physics and chemistry through the elegant application of mathematics, contributed to the development of the third law of thermodynamics. These studies dealing with matter at absolute zero were of practical importance for the field of cryogenics.

For a research project, Langmuir was assigned the rather mundane task of studying the chemical reactions of gases near a glowing platinum wire. Despite this unpromising situation, he was able to obtain excellent results. He used this research in his thesis to investigate the chemistry of gases and the transfer of heat from hot surfaces such as platinum wire.

LIFE'S WORK

Langmuir struggled trying to decide between a career in research at a university and a career as a chemist in industry. Perhaps by fate, his older brother Herbert wrote him a letter in which he detailed thoughts about this very question. Herbert advised a scholarly, scientific career but only if Irving was satisfied that he had the ability to

Irving Langmuir. (©The Nobel Foundation) make a great success of it. Irving believed in himself and knew his future direction.

After earning his Ph.D. in 1906, Langmuir began teaching chemistry at the new Stevens Institute of Technology in Hoboken, New Jersey. He was often praised for his teaching skills and his interest in the progress of young scientists, but he found the institute to be unbearable. He felt that his students had little interest in learning, his colleagues were lazy, and there was little opportunity for research. After three years, he resigned.

In the summer of 1909, he began working for the General Electric (GE) Research Laboratory in Schenectady, New York, where he would work for the rest of his life. The lab director, Willis R. Whitney, was recently recruited from the Massachusetts Institute of Technology (MIT) and had heard Langmuir at the conference that had brought him to Schenectady. The two men were assigned to work together, and GE's lab was an ideal place. Langmuir was at once taken by the latitude given to the scientists there and the easy rapport they enjoyed with one another.

Whitney had the task of building a great laboratory. He surrounded himself with the best men and allowed them to study whatever they wished without regard to practical outcome. This independence, he believed, would lead to useful product development, and the laboratory setting allowed him to assess new scientists.

Langmuir was drawn to research on gases in close proximity to a heated wire, work that resonated with his doctoral thesis. At that time, his new colleague, William David Coolidge, was working on a tungsten-filament lamp. It seemed logical that tungsten, which could withstand very high temperatures, would be superior to the carbon or tantalum then in use. The problem was that tungsten's brittle nature made it difficult to form into wires. Langmuir was fascinated by the problem and by GE's advanced equipment. He investigated what would happen if the gas in the light bulb was removed, and he discovered that the glowing tungsten wire produced a huge amount of gas inside the bulb. The tungsten-filament bulb blackened over time and the filament was short-lived. He soon discovered that a mixture of argon and nitrogen gases, along with a coiled filament, improved the light bulb's efficiency.

AN IMPROVED ELECTRIC LIGHT BULB

When Irving Langmuir began studying the electric light bulb at General Electric (GE) Research Laboratory, it was universally accepted that producing a vacuum in the bulb would preserve the tungsten filament and thereby prolong the life of the bulb. He had a passion for the extraordinary vacuum equipment available at GE's laboratory, and he designed a still better pumping apparatus. When he proposed to experiment with a light bulb filled with gas, however, even his boss, Willis R. Whitney, was doubtful.

A problem associated with designing a more efficient lamp was its tendency to blacken, or dim, after a period of use. Langmuir discovered that water vapor was the chief cause of the blackening, but only a small amount was required to produce it. After a great deal of effort, he learned just how complicated the process was. When the water vapor molecules come in contact with the hot filament, an oxygen compound of tungsten and atomic hydrogen is produced. The oxide of tungsten, which is easily converted to a gas, moves to the glass, where it is reduced by the atomic hydrogen and is deposited on the glass as metallic tungsten. Before Langmuir, no one had ever produced individual atoms of this highly reactive substance.

Further experiments demonstrated that even in the near absence of water vapor, the glass blackened at the same rate. Langmuir now concluded that a vacuum, no matter how perfect, was not going to improve the quality of the bulb. He turned his attention to other gases, such as nitrogen, in an effort to see if it too could be torn apart. It was not, but the life span of the bulb was markedly increased. It became apparent that the rate of evaporation of the tungsten was retarded by the gas molecules. He discovered that a nitrogen-argon mixture worked best.

In 1913, Langmuir applied for a patent for a gas-filled lamp, and it was granted three years later. Whitney estimated that Langmuir's work saved American consumers more that a million dollars every night on their lighting bills.

In 1912, Langmuir married Marion Mersereau, and they had two children, Kenneth and Barbara. Langmuir next turned his attention to surface chemistry. As early as 1916, he published in the *Journal of the American Chemical Society* an article concerning the fundamental properties of solids and liquids. A second part appeared in the same journal the next year, and a variety of reports appeared prior to his receiving the Nobel Prize in 1932. In presenting the new Nobel laureate to the audience in Stockholm, the chairman of the Nobel Committee for Chemistry described how Langmuir had radically changed the prevailing view of forces in thin films. Langmuir showed that films that were only one molecule thick behaved much like a two-dimensional gas. This daring point of view opened a new field of exploration.

Besides the Nobel Prize, Langmuir was awarded fifteen honorary degrees. Both the Royal Society of London and the American Chemical Society recognized his accomplishments with their most prestigious medals. Langmuir died of a heart attack in Falmouth, Massachusetts, in 1957.

IMPACT

Few scientists have contributed as much to pure research or have made as many practical contributions as Langmuir. He demonstrated an uncanny knack for seeing deeply into nature and understanding how his knowledge could influence real-world needs. Along with Willis R. Whitney, he appreciated both the importance and the joy of fundamental research. His research on the behavior of filaments led to the development of gas-filled incandescent bulbs that were significantly more efficient than other light bulbs, and his work in surface chemistry led to his revolutionary discovery that gases would adsorb onto the surface of a liquid or solid in a layer only one atom or molecule thick.

—*K. Thomas Finley*

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See also: Katharine Burr Blodgett; William David Coolidge; Lee De Forest; Thomas Alva Edison.

Great Lives from History

Inventors
& Inventions

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Inventors & Inventions

Volume 3

Lewis Howard Latimer - Charles Proteus Steinmetz

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LEWIS HOWARD LATIMER

American draftsman

Latimer's inventions ranged from improvements to the electric light bulb that facilitated its widespread manufacture and use to an advanced toilet system for railroad cars.

Born: September 4, 1848; Chelsea, Massachusetts
Died: December 11, 1928; Flushing, New York
Primary field: Electronics and electrical engineering
Primary invention: Carbon filament for the incandescent light bulb

EARLY LIFE

Lewis Howard Latimer was born to George and Rebecca Latimer in Chelsea, Massachusetts, in 1848. His parents had escaped from slavery in Virginia six years before Lewis, their fourth and last child, was born. He had two brothers and one sister. Lewis attended elementary school but was self-educated beyond that. He had great interest in reading, drawing, and learning about new things. By the time he was ten years old, he was working in his father's barbershop and as a paperhanger to help support the family.

In September, 1864, Latimer joined the U.S. Navy at the age of sixteen. He served on the USS *Massasoit* and remained in the Navy until the end of the Civil War, at which time he received an honorable discharge. After returning to the Boston area, he began work as an office boy for the patent law firm Crosby and Gould. While working there, he taught himself mechanical drawing by reading about it and by closely observing the draftsmen at the firm. When his capabilities were recognized, he was promoted to the position of draftsman by the firm. Latimer was married to Mary Wilson on December 10, 1873. The couple had two children—Emma Jeannette, born in 1883, and Louise Rebecca, born in 1890.

LIFE'S WORK

Latimer's first patent was for an improved toilet system to be used in railway cars and was called the "Water Closet for Railroad Cars" (U.S. Patent 147,363). The patent was issued to him jointly with Charles W. Brown on February 10, 1874. There is no evidence that he and Brown made serious efforts to market the device or that it came into widespread use. At this time, Latimer was working as a draftsman for Crosby and Gould, patent solicitors. Also while working there, he assisted Alexander Graham Bell by drafting the drawings of and helping in the patent application for his telephone invention. Through their joint efforts, the patent application was filed on February 14, 1876, just a few hours before a competitor. Bell was granted the patent on March 7.

In 1879, Latimer moved to Bridgeport, Connecticut, with his wife, his mother, and his brother William. In 1890, Latimer was hired as assistant manager and draftsman by Hiram Percy Maxim, owner of the U.S. Electric Lighting Company. Maxim was a rival of Thomas Alva Edison. While working for Maxim, Latimer learned quickly about the nascent electrical industry and was awarded three patents for devices and processes that improved the quality and efficiency of manufacturing electric light bulbs. The first patent (number 247,097) was for an "Electric Lamp," issued jointly to Latimer and Joseph V. Nichols on September 13, 1881. This invention was for an improved method of attaching the carbon filament to the wires used to bring electricity into the bulb. The second patent (number 252,386) was for a "Process of Manufacturing Carbons," issued to Latimer on January 17, 1882. This invention was an improved method of manufacturing the carbon filaments used for incandescent bulbs. The improved process produced longer-lasting carbon filaments. The third patent (number 255,212) was for a "Globe Supporter for Electric Lamps," issued to Latimer and John Tregoning on March 21, 1882. This was for an improved method of supporting arc lights. In addition to the three patented inventions, Latimer had many unpatented inventions that improved much of the equipment and many processes used in making electric lamps. In addition to his work in the manufacture of light bulbs, Latimer spent time assisting with installation of Maxim lighting equipment in Philadelphia, New York City, Montreal, and London. He spent nine months in London setting up a factory for producing Maxim electric lamps. His work included teaching the workers all of the processes used in making the lamps.

Latimer left the employ of U.S. Electric Lighting Company late in 1982, after returning from his assignment in London. For the next several years, he worked for several companies in the electrical industry. In 1885, he began a long period of employment with Edison Electric Light Company. He began in the engineering department, and in 1890 he moved to the legal department. He worked as a patent investigator and as an expert witness in cases against those trying to infringe on Edison patents. While working for the company, Latimer authored the book *Incandescent Electric Lighting: A Practical Description of the Edison System* (1890). In easy-to-understand language, the book described the entire system necessary for an incandescent lamp to produce light. There is some confusion about the authorship, however, because the above title by Latimer was published together with a paper by C. J. Field and a paper by John W. Howell, all in the same volume.

IMPROVED PROCESS FOR MANUFACTURING CARBON FILAMENTS

An incandescent light bulb produces light by passing electric current through a thin wire called a filament. The filament has adequate electrical resistance so that it heats to a high temperature when electric current is passed through it. The temperature is high enough to make the filament emit light, hence its glow. In order to be practical for use as a lighting device, the filament must be prevented from oxidizing (burning) and thus wearing out rapidly at the high temperatures. In early light bulbs, a carbon filament was used and a vacuum was drawn in the bulb to prevent oxidation. In modern bulbs, tungsten is used for the filament and the bulb is filled with an inert gas, usually argon, to prevent oxidation. This is done because tungsten would vaporize too rapidly in a vacuum. Also, the filament must be connected to a base with electrical conductors so that an electrical voltage can be applied in such a way that electric current will flow through the filament.

The invention of the incandescent light bulb was actually spread out over many years. In 1802, Sir Humphrey Davy passed enough direct current through a platinum strip to produce incandescent light. In the mid-to-late 1800’s, several other inventors experimented with use of some form of carbon for the filament and with drawing a vacuum in the bulb. In 1880, Thomas Alva Edison received a patent for improvements to the light bulb that made it practical to produce. In 1881 and 1882, Lewis Howard Latimer received patents for further improvements to the light bulb, especially the carbon filament. His improved process for manufacturing carbon filaments made them longer lasting and capable of more rapid production. He also made improvements to the light bulb production process. His improvements aided in bringing about production of high-quality bulbs in large numbers.

The incandescent light bulb was a very significant invention. It allowed people to work, travel, and carry out commerce at night. The previous sources of light, such as candles, fire, or oil lamps, made these activities difficult or nearly impossible to do at night. Work could now be done in factories over a twenty-four-hour period rather than in daylight hours only. Stores could stay open longer to do business. With the availability of the light bulb, mining became safer. Previously, lanterns had been used to provide light underground. The flames in lanterns consumed oxygen and added to the carbon dioxide content in the air, making breathing difficult. Also, the use of lanterns with an open flame was an explosion hazard underground.

When Edison Electric Light Company merged with Thomson-Houston in 1892 to form General Electric, Latimer continued in the legal department of the newly formed company until 1896, when he became chief draftsman for the Board of Patent Control, a joint arrangement between General Electric and Westinghouse Electric Company. He continued in this position until 1911, when he began work for a patent consulting firm headed by Edwin Hammer and Elmer Schwarz. He continued with them until 1922, when he retired because of failing eyesight.

Besides his inventions related to electric light bulbs and their manufacture, Latimer received patents for other devices, including an “Apparatus for Cooling and Disinfecting” (1886), a forerunner of the air conditioner; a device for locking hats, coats, and umbrellas on a hanging rack (1896); a book support (1905); and a lamp fixture (1910). He was a charter member of the Edison Pioneers, an exclusive group formed in 1918 and composed of men who were technical or business affiliates of Edison or one of his companies. The purpose of the group appeared to be primarily social and professional networking. Latimer’s wife died in 1924, and he passed away in his home in Flushing, New York, on December 11, 1928.

IMPACT

While Edison invented the first commercially practical incandescent light bulb (patent issued in 1880), it is less widely known that Latimer made important related inventions shortly afterward that made possible the efficient manufacture of high-quality light bulbs. The three patents Latimer was awarded while working for the U.S. Electric Lighting Company and the unpatented work he did in developing and improving the process of manufacturing electric light bulbs facilitated the widespread use of electric lighting. In addition, Latimer supervised the installation of carbon filament electric lighting in several major cities. He spent most of his career working in the newly developing electrical industry, using his talents as engineer, draftsman, and patent expert. Latimer was recognized for his work on electric filament manufacturing by his induction into the National Inventors Hall of Fame in 2006.

—*Harlan H. Bengtson*

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See also: Alexander Graham Bell; Sir Humphry Davy; Thomas Alva Edison; Sir John Harington; Hiram Percy Maxim; George Westinghouse; Granville T. Woods.

ERNEST ORLANDO LAWRENCE

American nuclear physicist

Lawrence was the inventor of the cyclotron, a circular particle accelerator that was widely used by scientists to study nuclear reactions and to produce new radioactive isotopes. During World War II, Lawrence supervised the magnetic separation of fissionable uranium 235 for the atomic bomb project.

Born: August 8, 1901; Canton, South Dakota
Died: August 27, 1958; Palo Alto, California
Primary fields: Military technology and weaponry; physics
Primary invention: Cyclotron

EARLY LIFE

Ernest Orlando Lawrence was born in Canton, South Dakota, a small farming community near the Minnesota border. Both his parents were descendants of recent immigrants from Norway. His father was superintendent of Canton City Schools and his mother had been a high school mathematics teacher. As a child, Lawrence showed an early interest in electrical apparatuses. At age nine, he and another boy learned to recharge old batteries, which they used to operate doorbells and electric motors. Later, the two friends built a radio receiver with a roof antenna that enabled them to receive messages from ships at sea. In 1916, Lawrence was the first person in the area to hear the news of Germany's declaration of war against the United States.

Lawrence graduated from high school in 1918. After one year at St. Olaf College in Minnesota, he transferred to the University of South Dakota (USD). At USD, Lawrence approached Professor Lewis Akeley, who taught electrical engineering and physics, about setting up a radio station on campus, which would provide good publicity for the university and give practical experience to engineering students. Lawrence had prepared a proposed budget with several levels of funding to accomplish different levels of operation. With Akeley's approval, Lawrence purchased the needed apparatuses and successfully got the station into operation.

Akeley was amazed that Lawrence knew so much about electricity without ever having taken a class in the subject. He offered to tutor him in physics during the summer, at which time they covered the material for a year's course in just six weeks. In his senior year, Lawrence was the only student to sign up for an advanced physics course. Realizing that this young man had a very special talent, Akeley proposed a novel class format: Lawrence would give all the lectures, while the professor became his student. In later years, Lawrence gave credit to Akeley for teaching him how to study a subject thoroughly. After graduating from USD in 1922, Lawrence obtained a physics fellowship for graduate work at the University of Minnesota.

LIFE'S WORK

At Minnesota, Lawrence came under the influence of Professor W. F. G. Swann, a dynamic young physicist who became his thesis adviser. The following year, Swann moved to the University of Chicago, where Lawrence followed him. At Chicago, Lawrence came into contact with world-renowned Nobel Prize laureates such as Albert A. Michelson and Robert Millikan. A year later, Swann accepted a professorship at Yale University, and Lawrence again followed his mentor. Lawrence received the Ph.D. from Yale in 1925 and was given a position as assistant professor.

In the next three years at Yale, Lawrence became recognized as an outstanding experimentalist. He published several notable papers on the interaction of light and electricity, using apparatuses that he designed and built. He did not enjoy teaching undergraduate students who had little interest in physics. In 1928, he was offered a position as associate professor at the University of California, Berkeley, which promised him time for research and teaching duties limited to graduate courses. He accepted enthusiastically. With his infectious optimism, after just one year he had become the thesis adviser for eight students. Through frequent publications and contact with scientists at other universities, he became nationally known. When he received employment offers from two rival universities, Berkeley decided to promote him to full professor at the young age of twenty-nine.

In the early 1930's, physicists were trying to go beyond natural radioactivity to probe the atomic nucleus. One technique was to build a high-voltage device, like an X-ray machine, that would accelerate particles to high energy for bombarding various targets. Lawrence had an alternative idea that many small accelerations at low voltage might overcome the difficulty of using a single stage of high voltage to reach the same final result. It would be like a boy on a swing who is given many small pushes instead of a single big push to pump him up. Using a magnet, Lawrence showed that particles could be forced to go in a circular path and would gain energy repeatedly each time they crossed the same electric acceleration region. In 1931, he was able to produce a circulating beam that reached a final energy equivalent to 1 million electronvolts using fewer than 20,000 electronvolts for each acceleration. Dozens of cyclotrons based on Lawrence's design were built at other universities while he pushed ahead to obtain higher particle energies. With his graduate students, he constructed a machine in 1936 having an electromagnet with a diameter of thirty-seven inches to produce protons with an energy equivalent to 80 million electronvolts. In 1939, Lawrence was awarded the Nobel Prize in Physics for his invention of the cyclotron and the production of new radioactive isotopes.

The fission of uranium was discovered in Germany in 1939. Scientists who recently had come from Europe were greatly alarmed that Germany would try to make an atomic

Ernest Orlando Lawrence makes adjustments to his cyclotron at the University of California, Berkeley, in 1939. (Getty Images) bomb based on fission. The American response was slow at first but eventually became a major war effort called the Manhattan Project. It was determined that only the rare isotope uranium 235, less than one percent of ordinary uranium, was fissionable. In 1941, Lawrence converted the Berkeley cyclotron to a mass separator and showed that a slight enrichment of U-235 could be obtained. Based on rather meager evidence, Lawrence proposed a major scaling up to construct a laboratory dedicated totally to U-235 enrichment. This laboratory, with ninety-six magnetic separators, was built at Oak Ridge, Tennessee, with Lawrence in charge. After some initial problems, the laboratory eventually operated around the clock and by early 1945 had produced several kilograms of U-235 with high enrichment. The material was shipped to Los Alamos, New Mexico, where the atomic bomb design and assembly were carried out.

After the end of World War II, Lawrence's scientific work decreased as he became more involved as a governmental adviser. Along with Edward Teller, he advocated the construction of the powerful hydrogen bomb, which is detonated by a fission bomb. He witnessed several nuclear test explosions in the South Pacific. Lawrence encouraged the Atomic Energy Commission to form a special laboratory for weapons research, now called the Lawrence Livermore National Laboratory. After his death in 1958, the artificially created element 103, first produced at Berkeley, was named Lawrencium in his honor.

THE CYCLOTRON

The cyclotron is a particle accelerator. Most commonly, the particles being accelerated are hydrogen ions, which are hydrogen atoms whose single orbital electron has been stripped off. The hydrogen ions, called protons, have a positive electric charge. When a voltage source is connected to two electrodes, a proton crossing the gap between them would gain kinetic energy. In 1929, Ernest Orlando Lawrence had the unique idea to use a magnetic field to deflect protons back into the acceleration region between two electrodes. By reversing the polarity of the voltage applied to the electrodes, the ions would gain more energy each time they crossed the gap. Lawrence's first experimental model used a magnet with a diameter of just four inches. He was successful in showing that the device, which he called a "proton merry-go-round," operated as intended.

The core of the cyclotron is a pair of D-shaped, hollow, metal electrodes separated by a small gap. To visualize this arrangement, one can imagine a round, flat can cut into halves, each piece having the shape of the letter *D*. When a proton crosses the gap between the two "dees," its kinetic energy increases in proportion to the applied voltage. The dees are placed into a strong magnetic field that curves the protons around in a semicircle, bringing them back to the gap between the dees. The protons gain another burst of kinetic energy if the voltage applied to the dees has been reversed and is synchronized with the arrival time of the protons. As the protons gain energy, they spiral outward because of their greater velocity. The strength and diameter of the magnet limit the maximum particle energy obtainable.

In 1939, construction had started on a sixty-inch model with a two-hundred-ton magnet, and a huge 184-inch-diameter machine was in the design stage. Work on these cyclotrons was discontinued when American scientists were mobilized for the war effort. The 184-inch cyclotron eventually was completed in the late 1940's. For higher energies, it is not practical to increase the magnet size. Modern accelerators are shaped like an enormous doughnut having a circumference up to four miles, using many small magnets along the periphery to produce protons having a final energy of billions of electronvolts. Modern accelerators are the descendants of the early cyclotrons, using magnetic deflection synchronized with repeated electric accelerations.

IMPACT

In the 1930's, cyclotrons were the primary tool to create new radioactive isotopes, some of which became useful in the medical profession. For example, radioactive iodine can be injected into a patient for cancer therapy of the thyroid gland. Radioactive sodium, calcium, and phosphorus have been widely used as tracers in biological and medical research. Nuclear medicine has become an important department in most large hospitals.

During World War II, many scientists who had prewar experience with nuclear technology were brought into the Manhattan Project. Their expertise with isotope separation, nuclear reactions, and radiation detectors were essential for the atomic bomb development. Lawrence earlier had justified his proposals for research funding from foundations and government agencies in part to provide training of young scientists for their potential future contributions to society.

Lawrence has been recognized as a leader in the development of "big science." He foresaw that only the federal government had the financial resources to fund large projects. The space program to put a man on the Moon, utilizing thousands of personnel and billions of dollars, was modeled after the Manhattan Project. Big accelerators, such as Fermilab near Chicago, typically employ hundreds of scientists and support staff. Research on alternative energy sources to reduce dependence on oil and coal is a current example of big science.

—*Hans G. Graetzer*

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See also: Frederick Gardner Cottrell; Donald A. Glaser; M. Stanley Livingston; J. Robert Oppenheimer; Glenn Theodore Seaborg; Edward Teller.

BILL LEAR

American electrical and aeronautical engineer

Lear is best known for his development of the Learjet, a sleek business jet aircraft capable of speeds exceeding 560 miles per hour. In addition, Lear invented the eight-track stereo music system and an autopilot system. He also made significant contributions to automobile radio technology and battery power storage.

Born: June 26, 1902; Hannibal, Missouri
Died: May 14, 1978; Reno, Nevada
Also known as: William Powell Lear (full name)
Primary fields: Aeronautics and aerospace technology; electronics and electrical engineering
Primary invention: Learjet

EARLY LIFE

William Powell Lear was born on June 26, 1902, in Hannibal, Missouri, to Reuben, a carpenter, and Gertrude Lear (Powell), a homemaker. Gertrude left Reuben in 1904 and took young Bill with her to Dubuque, Iowa, where they lived with an aunt. They later moved to Chicago, Illinois, with Otto Kirmse, a family friend. Otto was a hardworking man who had a significant positive influence on Lear.

Lear was educated in the public school system, choosing to leave school in the eighth grade. He spent a couple summers with his father, who had relocated to Oklahoma after separating from Gertrude. These trips often resulted in violent arguments between Lear and his mother. Lear worked odd jobs until joining the Navy as a radioman during World War I. Not unlike another famous Hannibal inhabitant, Mark Twain, Lear was quite the iconoclast. An independent thinker and outspoken individual, Lear did not hesitate to frequently correct his teachers and Navy instructors when they were in error. This habit did not endear him to his instructors and resulted, more than once, in his being asked to leave the class and not return. With the exception of training received in the Navy, the eight years Lear spent in elementary school were the sum of his formal education. Lear was married four times and fathered seven children. He was married to his fourth wife, Moya, for the longest period, staying with her until his death.

LIFE'S WORK

After being discharged from the Navy, Lear worked a short stint in an auto supply store in Quincy, Illinois, representing himself as a radio engineer. While working there, he built his first radio and went into business with a prominent Quincy businessman manufacturing radio receivers. During this time, Lear and his first wife, Ethel, lost a child (William P. Lear, Jr.) to crib death (now called sudden infant death syndrome). The death played a role in Lear's leaving Ethel, moving back to Chicago, and marrying Madeline Murphy in 1926. In Chicago, Lear continued his entrepreneurship, creating a B-battery eliminator, which solved the need for using batteries to supply direct current for commercial radio receivers. He designed a power inverter that converted alternating current to direct current, which in turn supplied the necessary receiver power.

Lear then began a series of short-lived jobs at ever-increasing salaries. At each job, his clear thinking and innovative approach helped him find ways to maximize electronics performance and simplify associated systems. While working for Galvin Manufacturing Corporation, he designed a car radio called the Motorola. This device became the first major product of the Motorola Corporation (formerly Galvin Manufacturing). Lear was doing well financially, earning a $35,000 salary, an incredible sum in 1931. Some of this money went to flying lessons. After only two and a half hours of flight instruction, Lear made an unauthorized solo flight. Lear's introduction to flying would prove to be auspicious, as it led him to develop an automatic pilot system and ultimately to his crowning life achievement of developing the revolutionary Learjet.

A prototype Learjet 23 on a test flight in February, 1964. (Getty Images)

Lear divorced his second wife and moved to New York City with his third wife, Margaret Radel. It was a short-lived marriage. In New York, Lear met Russell King of the Radio Corporation of America (RCA). Lear pitched an idea to King regarding the production of a standardized chassis for "all-wave" (multiband) radio receivers. King jumped at the idea, paying Lear $50,000 cash for it and agreeing to pay him an annual consultancy fee of $25,000 for the next five years. In 1942, Lear met and married the woman who turned out to be the love of his life, Moya Olsen. Bill and Moya would remain married for thirty-six years, the remainder of Lear's life.

Lear had founded an aircraft instrument business, Lear, Inc., in 1939 and begun development and production of airplane autopilot units. The business, based in Grand Rapids, Michigan, filled a number of orders for the Allied effort during World War II. Lear later sold a large portion of the business to the Siegler Corporation, which later became Lear-Siegler. Lear stayed on with the company, and he and Moya relocated to Santa Monica, California. The autopilot that Lear invented resulted in his being awarded the prestigious Collier Trophy in 1950. In 1951, Lear was awarded an honorary engineering degree from the University of Michigan recognizing his innovations and inventions in electronics.

As the 1950's came to a close, Lear proposed to the executives at Lear-Siegler his idea for a radical new business airplane design. The aircraft would be a small private jet capable of flying faster that the most modern airliners. Lear-Siegler immediately struck down the idea, citing the huge financial risk of such a project. Never one to tolerate resistance to his ideas, Lear sold his interest in Lear-Siegler for more than $14 million and took his Learjet idea with him.

Lear established a research and manufacturing facility for the Learjet in Switzerland but then relocated the facility to Wichita, Kansas, in 1962. The Learjet would prove to be a paradigm-altering aircraft that brought the business and entertainment world into the jet age. Capable of cruising at 560 miles per hour at altitudes in excess of 40,000 feet, the Learjet appealed to busy, albeit rich, travelers. One hundred four Learjet 23's were manufactured between 1962 and 1966.

LEARJET AIRCRAFT

Bill Lear's early forays into electronic inventions such as the B-battery eliminator, the first practical car radio, and aircraft autopilots were precursors to his crowning invention, the Learjet 23. Lear's devotion to simplicity of design, fueled by his innovative mind, paid off in the design of the Learjet 23. The aircraft was first flown on October 7, 1963, and the first production model was delivered only one year later, on October 13, 1964.

The Learjet 23 was a distinctive presence on airport ramps. With clean, aerodynamic lines, it was powered by two General Electric CJ610-4 turbojet engines. The aircraft was capable of flying 560 miles per hour and achieving a service ceiling of over 44,000 feet. Range was approximately 2,500 statute miles. With an empty weight of 6,151 pounds and a maximum gross takeoff weight of 12,499 pounds, the Learjet could have served as a prototype for the modern very light jet (VLJ). The Learjet design incorporated swept wings, maximizing the aircraft's aerodynamic efficiency. At high, transonic speeds, which the Learjet was capable of achieving, air traveling over the upper surface of the wing accelerates to supersonic speeds, forming a wave of compressed air (shock wave) ahead of the wing. The shock wave causes drag, which must be overcome with additional thrust. Making the wing less curved and as thin as possible reduces the potential of airflow accelerating to supersonic speeds and retards the formation of a shock wave. Unfortunately, thin, flat wings produce significantly reduced lift when compared to thick, curved wings. To overcome this lift deficit, Lear swept the Learjet's wings aft, effectively increasing the wing's area while retaining the thin, flat design that was essential to mitigating shock-wave effects.

One hundred four Learjet 23's were produced between 1962 and 1966. A number of other models were later produced. The Learjet was the ultimate status symbol for the rich and powerful during the 1960's and 1970's. Corporate leaders, actors, government officials, and rock stars traveled in the swift opulence provided by Lear's invention. The timelessness of the Learjet is illustrated by the influence of its design. Both the Canadair CL-600 Challenger Jet and the Canadair Regional Jet (CRJ) owe a great deal of their design heritage to the Lear Star 600, a design derivative of the Learjet 23. Both the Challenger and the CRJ are hugely successful aircraft, the Challenger as a luxury business jet and the CRJ as a workhorse within regional airlines.

Interestingly, the Learjet design and production process led to Lear's invention of the eight-track tape system. Seeking an efficient music delivery system for the Learjet, Lear tweaked the existing four-track system to create the very popular eight-track stereo cartridge and playback system.

In later life, Lear became greatly concerned about air pollution. He made a valiant attempt at reviving the concept of the steam car. Investing millions of dollars in research and production, Lear tried unsuccessfully to produce a cost-effective and efficient steam turbine vehicle. Lear perceived the U.S. government as being obstructionist and unsupportive of his efforts. His frankness and disregard for the standard niceties of addressing government officials did not help his efforts to win government appropriations for his work. Giving up on his quest for steam locomotion, Lear again turned his sights on aviation. During the mid- to late 1970's, Lear worked diligently on his latest aircraft design, the Lear Fan, another new concept aircraft. Utilizing composite construction, the Lear Fan was powered by twin turboshaft engines driving a pusher propeller. The aircraft was capable of being flown by a single pilot, could carry eight passengers, and burned approximately two-thirds less fuel than aircraft with similar capabilities. Sadly, Lear would never see his Lear Fan fly. Diagnosed with leukemia, Lear succumbed to the disease on May 14, 1978, in Reno, Nevada, leaving Moya to run the business.

IMPACT

Lear ushered in the era of the small business jet. His enthusiasm, innovativeness, and determination to succeed at all costs were remarkable. Many have said that people either loved or hated Lear; there was no middle ground. Although an adherent to the autocratic management style, Lear had an uncanny ability to influence key subordinates who helped steer his projects to success. A lasting testament to Lear's innovativeness and design prowess is the hugely successful Canadair Regional Jet (CRJ), produced by Bombardier. The CRJ is largely based on the design of a later Learjet aircraft, the Lear Star 600.

—*Alan S. Frazier*

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See also: Hans Joachim Pabst von Ohain; Burt Rutan; Andrei Nikolayevich Tupolev; Mark Twain; Sir Frank Whittle.

HUGH LE CAINE

Canadian physicist and music composer

Le Caine was one of the founders of the field of electronic music, inventing such instruments as the Electronic Sackbut and the Special Purpose Tape Recorder for composition and performance.

Born: May 27, 1914; Port Arthur (now Thunder Bay), Ontario, Canada
Died: July 3, 1977; Ottawa, Ontario, Canada
Primary fields: Music; physics
Primary invention: Electronic Sackbut

EARLY LIFE

Hugh Le Caine (leh KEHN) was born in Port Arthur, Ontario, Canada. From childhood, he was fascinated by both music and science. He studied piano and began to envision the possibility of utilizing techniques used in science to invent musical instruments. Le Caine enrolled at Queen's University in the Department of Applied Science and studied physics. He received his bachelor of science degree in 1938 and his master of science degree in 1939. That year, he was also awarded a National Research Council (NRC) fellowship, which enabled him to remain at Queen's to do additional research. This was the beginning of a long relationship between Le Caine and the NRC, as he worked with the council from 1940 to 1974.

During his graduate studies, Le Caine became involved in atomic physics and made important technical improvements to several of the measuring devices used in the field. He also made significant contributions to the development of the first radar systems. The papers he presented and the articles he published earned him acclaim as a scientist in both fields. In 1948, he received another research grant from the NRC. This grant enabled him to study nuclear physics in England from 1948 to 1952. He received a Ph.D. from the University of Birmingham in 1952.

LIFE'S WORK

While studying physics, Le Caine still maintained his interest in music and also developed a fascination with motorcycles, which he enjoyed riding at high speeds. He actually set speed records, though unofficial, for the distance from Montreal to northern Ontario. While these feats impressed his friends and colleagues, his innovative activity in music was of much greater consequence. He tried applying the scientific techniques he was learning to the invention of musical instruments. In 1937, he invented an electronic free reed organ. In 1945, he set up a studio in his home; there he worked on developing electronic instruments, including the Electronic Sackbut, the first synthesizer ever built. He regularly had weekend jam sessions in his studio with his friends Bill Farrow and Mal Clark, his colleagues in physics.

Le Caine also started developing a polyphonic touch-sensitive organ and a device capable of simultaneously playing several tape recordings. His demonstrations of these instruments to the public made such a strong impression that in 1954 the NRC invited him to move his work to its facilities. The NRC provided him with a studio where he could work on his various projects. There he invented the Multi-track (Special Purpose) Tape Recorder. This device had the capability of simultaneously changing the playback speed of several recordings through the use of a keyboard.

Le Caine also composed music using the recorder. His purpose in composing was to understand the needs of the composer and to demonstrate the capabilities of his instruments. In 1955, he composed a piece called "Dripsody." It was created using the sound of a single drop of water falling. Le Caine continued to experiment with a variety of techniques for producing and controlling sound. As a result of his experimental work, he built more than twenty-two new instruments.

Le Caine was instrumental in the creation of Canada's first electronic music studio, which was installed at the University of Toronto in 1959. The studio was equipped with the various components of the Electronic Sackbut; Le Caine made the parts available as individual units.

THE ELECTRONIC SACKBUT

Hugh Le Caine built the first voltage-controlled electronic synthesizer; he called his monophonic instrument the Electronic Sackbut. "Sackbut" was an eighteenth century word for the trombone and comes from the Old French word *sacqueboute* ("pull-push"). It is assumed that Le Caine took the name from this origin. Employed at the time by the Canadian National Research Council as an atomic physicist, Le Caine began working on the Electronic Sackbut in his home studio in 1945. He modified and improved the design from 1945 to 1973. He built his first Sackbut inside a desk. It had a keyboard that enabled the operator to control three aspects of sound: Vertical pressure controlled volume, lateral pressure changed pitch, and timbre was controlled by pressure away from the operator. Since the controls were force-sensitive and changes in pressure caused them to alter the sound, the operator could play the instrument without watching the controls.

Le Caine did not complete a free-standing prototype of his instrument until 1948. This version of the Electronic Sackbut was built on a rather primitive three-legged stand with crosspieces reinforcing it. When playing the instrument, the operator controlled the keyboard with the right hand. One note was played at a time with both vertical pressure and lateral pressure being applied. By 1948, Le Caine had further developed the timbre control, giving the instrument greater complexity and requiring multiple devices for it to function. The left hand was used to control the various aspects of timbre; each finger of the left hand operated a separate pressure-sensitive control. The index finger was used to work a device that continuously altered the waveform. This enabled the operator to produce the sound of six different instruments—oboe, trumpet, clarinet, flute, strings, and organ—as well as organ mutation tones and foundation tones. This Electronic Sackbut is now housed in the Canadian National Museum of Science and Technology.

In 1969, Le Caine started to redesign the 1948 Electronic Sackbut, which he had modified considerably through 1956, and to incorporate modern techniques into the design. He paid special attention to enhancing the pressure-sensitive controls. In 1971, he demonstrated a new prototype that used integrated circuits for the level controls. The octave range had been increased from six to seven. The envelope control had been modified so that it could be played in reverse without any extra adjustment. He also added a device to adjust the wave shape. At this time, Le Caine was already thinking about a Sackbut that would have three oscillators, but he did not live to build it.

While Le Caine performed many public demonstrations of the Electronic Sackbut, it was never commercially marketed, remaining in the realm of academic research and invention. However, the instrument, with its use of adjustable waveforms for timbres and its use of voltage control, is recognized as the predecessor of the electronic synthesizers developed in the 1970's.

These could be used for specific tasks and in varied sequences, thus giving composers a true laboratory in which to experiment. In 1964, Le Caine collaborated on the installation of an electronic music studio at McGill University. It was in Le Caine's laboratory studio at the NRC that the equipment used in both these studios was developed. In 1966, he began teaching at both universities and presented seminars on electronic music.

During his lifetime, Le Caine received many awards and recognitions for his inventions and contributions to the new field of electronic music. In 1971, McGill University awarded him an honorary doctorate of music; in 1974, he received an honorary LL.D. from the University of Toronto. Also in 1974, Queen's University presented him with an honorary doctorate of music and named the Harrison-Le Caine Hall on its campus in his honor. In 1971, Le Caine attempted to commercially market the Electronic Sackbut but met with little success. In 1974, he retired from the National Research Council. On July 4, 1976, he was involved in a serious motorcycle accident; his injuries resulted in his death on July 3, 1977, in Ottawa.

After his death, Le Caine continued to receive honors for his many contributions to electronic music both as an inventor of instruments and as a composer of music. In 1978, the Hugh Le Caine Project was organized by the Canadian Electronic Ensemble to disseminate information about Le Caine. The ensemble began publishing a newsletter in June, 1979, and also played a minimum of one Le Caine composition at each of its concerts during the 1978-1979 season.

IMPACT

Le Caine was one of the pioneers in electronic music. With the invention of the Electronic Sackbut, he created the first voltage-controlled synthesizer. Using the various components of this instrument, he equipped the first two electronic music studios in Canada and provided the technical equipment needed for early composers of experimental electronic music.

Le Caine also wrote a large number of articles about his work in electronic music and gave numerous public demonstrations of the twenty-two instruments he developed. He also wrote thirty-eight electronic music compositions to demonstrate the capabilities of his instruments. In this way, he disseminated information about this new form of music and the instruments required to compose and perform it.

Through his teaching at the University of Toronto and McGill University, he had a significant impact on an entire generation of electronic-music composers. Le Caine played a significant though indirect role in the development of the first commercially successful electronic synthesizer. Gustav Ciamaga studied composition at the University of Toronto and knew about the filters Le Caine had developed. It was Ciamaga who influenced Robert Moog to invent the voltage-controlled low-pass filter used in his modular Moog synthesizer, and it was the Moog synthesizer that really gave impetus to the field of electronic music.

—*Shawncey Webb*

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See also: Ray Kurzweil; Robert Moog; Les Paul.

ROBERT STEVEN LEDLEY

American physicist and radiologist

Ledley's automatic computerized transverse axial (ACTA) X-ray scanner, the first whole-body computed tomography machine, allowed doctors to view three-dimensional X-rays of the body.

Born: June 28, 1926; New York, New York
Primary fields: Computer science; medicine and medical technology
Primary invention: Automatic computerized transverse axial (ACTA) X-ray scanner

EARLY LIFE

Born in New York City in 1926, Robert Steven Ledley earned a D.D.S. from New York University in 1948 and an M.A. from Columbia University in 1949. In 1950, he served in the U.S. Army Dental Corps. There he learned to use a Standards Electronic/Eastern Automatic Computer (SEAC) computer for research and befriended the engineers who built it. This was an auspicious beginning for the young doctor, who later pioneered the use of digital computers in medicine.

After serving in the Army, Ledley worked at the National Bureau of Standards (now the National Institute of Standards and Technology) in Washington, D.C. He then worked as a physicist and research analyst for Johns Hopkins University. From 1968 to 1970, he taught electrical engineering at George Washington University. In 1970, he joined the faculty at the School of Medicine at Georgetown University Medical Center as a professor of physiology and biophysics. There he would develop his ideas for the automatic computerized transverse axial (ACTA) X-ray scanner, the invention for which he is best known. In 1974, he became a professor in the Department of Radiology. The following year, he was appointed director of the Medical Computing and Biophysics Division, a position he held for more than thirty years.

LIFE'S WORK

Ledley contributed extensively to the field of medical informatics, in which computers and information technology help doctors diagnose and treat patients. Two of his publications laid the groundwork for this field: "Reasoning Foundations of Medical Diagnosis" (1959; published with Lee B. Lusted) and the college textbook *Use of Computers in Biology and Medicine* (1965). During the 1960's, Ledley began to develop genetic databases, another important contribution to medical informatics. In July, 1960, he established the National Biomedical Research Foundation (NBRF), where his first project involved the computerized analysis of human chromosomes. He designed a flying-spot scanner to digitize chromosome images and developed pattern-recognition algorithms to identify the chromosomes. Ledley has been president of the NBRF since its inception.

In 1970, one of Ledley's colleagues referred him to Alfred Luessenhop, chief of neurosurgery at Georgetown University Medical Center, who was interested in buying a brain scanner and had a brochure for a Hounsfield computed tomography (CT) scanner. Ledley read the brochure and was unimpressed with the device's description and design. Inspired by an article on CT scanning by South African physicist Allan M. Cormack, Ledley offered to build an ACTA scanner—the first whole-body CT scanner. Thus, he secured $250,000 from the NBRF to begin work.

Ledley believed that he could build his scanner based on his own design. At the project's outset, he utilized the expertise of mechanical engineers, but in the end he relied on himself to draw the designs. By 1973, his scanner was operational. He delivered lectures on his ACTA scanner, and he received praise for its use in medical diagnoses and its potential to save lives. As demand for the scanner increased, Ledley started his own manufacturing company, called the Digital Information Science Corporation (DISCO). It was difficult for him to fill all of his orders. When he failed to obtain a loan from a bank, he kept himself in business by asking for advances on each of the machines he built.

Ledley focused on teaching, inventing, and writing throughout his career. During his tenure at Georgetown University, he was the editor in chief of four scientific journals. In 1990, he was inducted into the National Inventors Hall of Fame for his invention of the whole-body CT scanner. In 1997, he was awarded the National Medal of Technology by President Bill Clinton for his contribution to radiology. In 1998, the National Institute of Dental Research recognized Ledley's work to improve dentures. After his retirement in the late 1990's, he continued to pursue his passion—inventing machines.

THE ACTA SCANNER

Robert Steven Ledley was the first inventor to develop a digital scanner that could take three-dimensional X rays of the entire human body. On November 25, 1975, Ledley received U.S. Patent number 3,922,552 for his automatic computerized transverse axial (ACTA) diagnostic X-ray scanner. It was first put into clinical operation in 1973. Ledley's scanner was based on the work of South African physicist Allan M. Cormack of Tufts University and English electrical engineer Godfrey Newbold Hounsfield, who had built the first computed tomography (CT), or computerized axial tomography (CAT), scanner. Having read a description of Hounsfield's device, which could scan only the head, Ledley set to work on designing a less expensive, better machine (that could scan any part of the body) for the Georgetown University Medical Center.

Ledley's ACTA scanner revolutionized medicine, providing doctors with an accurate method for diagnosing cancers, soft-tissue irregularities, and other medical conditions. The device works by obtaining cross-sectional X-ray images of a section of the body and piecing together those images using a computer. Whereas a single X-ray presents only a two-dimensional view, a CT scan presents a more detailed, three-dimensional view that allows doctors to see inside organs without surgery. Though noninvasive, the procedure exposes the patient to a high dose of radiation.

IMPACT

Ledley is a retired dentist, physicist, and inventor whose keen ability to visualize and create digital machines for medical purposes has led to significant advances in the field of diagnostic medicine. He spent countless hours in his office laboratory drawing his designs, reflecting on the materials needed to produce his machines, and developing groundbreaking digital programs to produce his inventions. His whole-body CT scanner proved revolutionary in a number of medical fields, including radiology, nursing, and surgery. The CT scan is a noninvasive procedure that allows doctors to see the internal structures of the body to locate tumors and infections. Ledley's work mapping human chromosomes made it possible to scan chromosomes for abnormalities such as Down syndrome. He also developed a three-dimensional fetus scanner that provided clearer images than those of sonograms. Ledley holds more than sixty patents.

—*Wladina Antoine*

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See also: Raymond Damadian; Wilson Greatbatch; Godfrey Newbold Hounsfield; Alec Jeffreys; Mary-Claire King; Willem Johan Kolff; Ray Kurzweil; René-Théophile-Hyacinthe Laënnec; Kary B. Mullis; Naomi L. Nakao; Wilhelm Conrad Röntgen.

ANTONI VAN LEEUWENHOEK

Dutch microbiologist

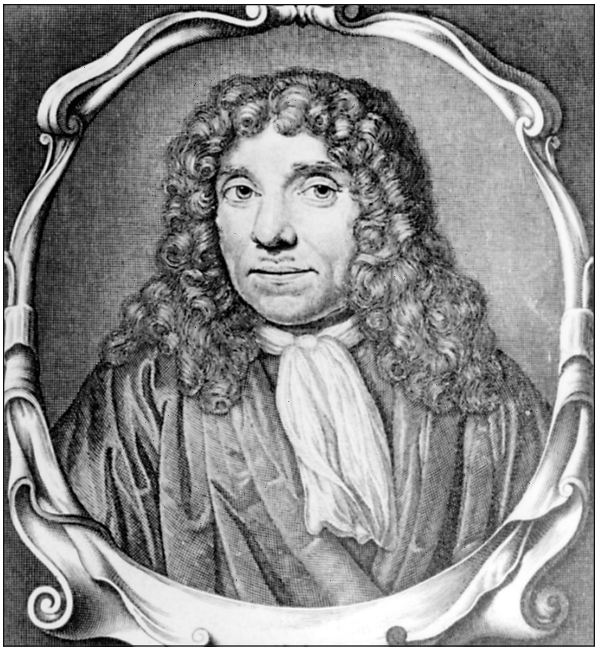
Leeuwenhoek designed and constructed many simple microscopes, perfecting an already existing device and adapting it to scientific use. He used the microscope to discover the existence of microorganisms and introduce them to science.

Born: October 24, 1632; Delft, Holland, United Provinces (now in the Netherlands)
Died: August 26, 1723; Delft, Holland, United Provinces (now in the Netherlands)
Also known as: Thonius Philips van Leeuwenhoek (birth name)
Primary fields: Biology; medicine and medical technology
Primary invention: Simple microscope

EARLY LIFE

Antoni van Leeuwenhoek (LAY-vehn-hook) was born to a family of tradespeople. His father, Philips Thonisz, was a basket maker, and his mother, Grietje van den Berch, was the daughter of a brewer. After his father died in 1638, Leeuwenhoek was sent to the town of Warmond to attend school. Upon completion of his basic education, he went to live with his uncle in Benthuizen for further education. When his uncle died in 1648, his mother sent Leeuwenhoek to Amsterdam, where he lived with his mother's brother-in-law and learned the trade of a draper (fabric merchant). While in Amsterdam, Leeuwenhoek saw mounted magnifying glasses that were used by textile merchants to examine the quality of cloth. These were probably the paradigm for the simple microscopes he later made.

In 1654, Leeuwenhoek returned to Delft and married Barbara de Mey, who gave birth to five children. She died in 1666, and Leeuwenhoek remarried in 1671. He bought a house and a shop and launched a fabric busi-



Antoni van Leeuwenhoek. (Library of Congress) ness. In addition to being a fabric merchant, Leeuwenhoek also worked as a surveyor, wine assayer, and a minor city official, which provided him with a permanent income.

LIFE'S WORK

Some time before 1668, Leeuwenhoek learned to grind lenses and to use them to make simple microscopes, which he used to observe various objects. The inspiration for Leeuwenhoek's microscopic work seems to have been the research of the English scientist Robert Hooke, who designed and built a compound microscope, which he used to examine a wide variety of living and nonliving specimens. Hooke's illustrated book, *Micrographia* (1665), which contained detailed drawings of his observations, was very popular and heavily influenced Leeuwenhoek.

Leeuwenhoek's scientific investigations were widely read because he reported them to the Royal Society of London. He became known to the Royal Society in 1673 when a brilliant young Delft physician, Regnier de Graaf, wrote to Henry Oldenburg, the secretary of the Royal Society of London, about Leeuwenhoek's observations. Oldenburg was intrigued by de Graaf's reports and initiated contact with Leeuwenhoek, who sent the first of what would be a long series of letters to the Royal Society that described his scientific investigations. Leeuwenhoek's letters were translated from Dutch into English or Latin and published in the *Philosophical Transactions of the Royal Society*. The conversational style of these letters is filled with exacting and careful descriptions of what he observed through his microscope.

As a pioneer in the study of microscopic life, Leeuwenhoek described many new microscopic species. In 1674, he described protozoa from fresh pond water and identified the green alga *Spirogyra* in lake water, and several other free-living protozoa, such as *Vorticella*. He also described the colonial green alga *Volvox* and experimentally showed that it underwent reproduction instead of arising from nonliving matter (spontaneous generation). Leeuwenhoek also was the first to observe and describe the parasitic protozoan *Giardia*, which he incidentally encountered while observing material from his own feces. He also discovered microscopic animals called rotifers and established their unique ability to withstand desiccation.

In 1676, Leeuwenhoek's relationship with the Royal Society experienced some strain when he became the first person to observe and describe bacteria. Leeuwenhoek reported tiny, microscopic organisms in a water preparation of peppercorns. Because the seventeenth century concept of life did not accommodate organisms whose diminutive nature rendered them invisible to the naked eye, the Royal Society viewed his initial report with considerable skepticism. However, after sending representatives to Holland who corroborated Leeuwenhoek's observations, the Royal Society welcomed his reports of microorganisms. The Royal Society rewarded Leeuwenhoek's exacting and reliable observations by electing him to be a full fellow of the society in 1680.

Perhaps Leeuwenhoek's most famous finding was recorded in his September 17, 1683, letter to the Royal Society about observations of the plaque between his own teeth. This whitish material was teeming with swimming bacteria, which he referred to as "animalcules." These bacteria disappeared after drinking hot coffee but reappeared soon thereafter. His descriptions of oral bacteria are so detailed that it is possible to determine which bacterial species he saw.

Leeuwenhoek was a keen observer of nature who had an unusual eye for microscopic detail. He was one of the first people to examine fresh semen and observe living spermatozoa, which led him to propose that fertilization occurred once spermatozoa penetrated the egg. He also discovered lymphatic capillaries in the intestine in 1683 and, in 1688, documented the circulation of red blood cells through blood vessels in the tails of tadpoles. Leeuwenhoek elucidated the fine, microscopic structure of the human spleen (1706), striated (voluntary) muscle (1714), the eye and its optic nerve, and bone (1720). He even described a way to stain transparent muscle fibers with a solution of saffron in brandy.

However, Leeuwenhoek was not just an observer but also a talented experimentalist who developed new techniques and perfected older ones. One such technique extensively used by Leeuwenhoek was microdissection. He used his microscope to guide dissections of very small organisms in order to probe a wide variety of questions. Dissection of aphids, for example, showed that the bodies of adult aphids were filled with young aphids, demonstrating that these tiny insects were born and not spontaneously generated. Microdissections of ovaries from freshwater mussels (*Unio*) revealed spinning mussel embryos, a discovery that called into question Aristotle's idea that mussels and other shellfish are generated from mud or sand at low water. Other microdissections involving plant material not only elucidated the internal structure of plant stems and roots (he described the different structure of the stem of monocotyledonous and dicotyledonous plants) but also provided insights into plant seeds and embryos.

Leeuwenhoek also used his microscopes and microdissection to document parasitism in a wide variety of plants and animals. Beginning in 1695, Leeuwenhoek examined the parasitism of aphids and found empty aphid exoskeletons with small holes bored in them. Leeuwenhoek correctly surmised that the parasite had emerged through this hole. He also microdissected immobile aphids and showed that their entire internal body cavities were filled with larval wasps (Leeuwenhoek referred to them as "ants"). Leeuwenhoek observed the female wasp use her ovipositor "in the manner of a sting" to inject eggs into the host insect. He utilized a confined chamber to isolate infected host insects so he could watch the parasites emerge; in doing so, Leeuwenhoek characterized the life cycle of aphid parasitoid wasps. Leeuwenhoek also examined plant parasites and showed that the larval stages of particular insects were responsible for the formation of galls on the leaves of oak and thistles.

Many distinguished individuals showed interest in Leeuwenhoek's remarkable findings. Heads of state that included Queen Mary of England and Russian czar Peter the Great visited Leeuwenhoek at his home in Holland to view his microscopic images. Leeuwenhoek continued his experiments even until his last days. When Leeuwenhoek died, the pastor of New Church in Delft wrote to the Royal Society, "Antony van Leeuwenhoek considered that what is true in natural philosophy can be most fruitfully investigated by the experimental method."

THE SIMPLE MICROSCOPE

Simple microscopes use one lens to magnify the specimen, while compound microscopes use a magnifying lens plus an eyepiece lens to multiply the magnification. Compound microscopes were invented around 1595, nearly forty years before Antoni van Leeuwenhoek was born. Two contemporaries of Antoni van Leeuwenhoek, English scientist Robert Hooke and Dutch scientist Jan Swammerdam, built compound microscopes and made important discoveries with them.

Leeuwenhoek made simple microscopes, but his skill as a lens crafter allowed him to make instruments whose magnifying power and clarity were better than the compound microscopes used by other scientists of his time. Therefore, while it is incorrect to designate Leeuwenhoek as the inventor of the microscope, he perfected the simple microscope and was a talented lens grinder and microscope maker. Leeuwenhoek made more than four hundred microscopes, of which fewer than ten survive today, and manufactured more than five hundred microscope lenses.

The microscopes made by Leeuwenhoek had the same basic design as a magnifying glass. Compared to the microscopes of today, they were exceedingly simple. They used one lens mounted in a small hole within a metal plate to which a brace was attached for holding a handle and a specimen mounting device. The specimen was mounted on a sharp point that extended toward the lens and held the specimen in front of it. The position of the specimen could be adjusted by two screws located on the brace, which were also used to focus the image. The whole instrument was quite small—only three to four inches long—and had to be held very close to the eye in order to properly see the magnified image. Because this simple microscope had no built-in light source, candlelight was probably used to illuminate the image. It is clear that the use of this instrument required a great deal of patience.

Technical difficulties prevented compound microscopes from being able to magnify objects more than twenty or thirty times their size. However, Leeuwenhoek's skill as a lens grinder enabled him to make microscopes that magnified objects more than two hundred times their normal size. This technical advantage—combined with his naturally acute eyesight, great care, detail in describing what he saw, and monumental patience—allowed Leeuwenhoek to use his microscope to view just about anything and gain significant insight from it.

IMPACT

Even though Leeuwenhoek did not invent the microscope, he perfected the simple microscope and also demonstrated the power of microscopy when wielded by an inquisitive investigator. Therefore, it is apt to call Leeuwenhoek "the father of microscopy." However, Leeuwenhoek is best known for his discovery of microorganisms, which introduced science to a world that was previously completely unknown. The discovery of microorganisms initiated the science of microbiology, and this led to the discovery of the germ theory of disease and, eventually, treatments for infectious diseases. Modern medical advances began with Leeuwenhoek's observations of microbes.

Even though his discovery of microbes tends to overshadow his other achievements, Leeuwenhoek was also a pioneer in the field of parasitology. His documentation of parasitism launched a previously unknown field and placed it on firm experimental grounds.

Leeuwenhoek was not only an observational microscopist but also an experimentalist who contributed to the birth of modern science by demonstrating the power of empirical data gathering and the experimental method. Much of his work powerfully refuted the prevailing theory of spontaneous generation. Furthermore, his skills as a section cutter (microtomist) and microdissector distinguish him as a pioneer of eighteenth century experimental biology.

—*Michael A. Buratovich*

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See also: Roger Bacon; Robert Hooke; Zacharias Janssen; Louis Pasteur.

GOTTFRIED WILHELM LEIBNIZ

German philosopher and mathematician

Leibniz's calculating machine did not have much influence on the subsequent development of computers. His vision of a mechanical way of settling arguments and disputes proved far more influential, even if he could not make much headway himself in translating his vision into reality.

Born: July 1, 1646; Leipzig, Saxony (now in Germany)
Died: November 14, 1716; Hanover (now in Germany)
Primary field: Mathematics
Primary inventions: Calculus; Leibniz's calculator

EARLY LIFE

Gottfried Wilhelm Leibniz (GOT-freed VIHL-hehlm LIB-nihts), one of the most wide-ranging intellects in the history of thought, was the son of Friedrich Leibniz and his third wife, Catharina Schmuck. The family was of noble and scholarly ancestry on both sides, and Gottfried's father early saw signs of great talent in his son. Friedrich Leibniz died when his son was six, but the family was financially well enough off to guarantee that Gottfried was able to get the best education. He attended a private school from 1653 to 1661, although he was more influenced during this period by the freedom to range through his late father's library.

In 1661, Leibniz enrolled at the University of Leipzig, where his interests took him in many directions. He studied the traditional discipline of Aristotelian metaphysics, but he also spent time at the University of Jena learning about mathematics. In general, he found mathematics appealing because it provided a degree of certainty that philosophy could not achieve. He pursued further research in philosophy at the same time that he was pursuing the study of law. His original application for a doctorate in law was deferred by the University of Leipzig, which Leibniz claimed to have been based on the legal community's efforts to reduce the flow of new lawyers into the profession. As a result, he transferred to the University of Altdorf in Nuremberg, submitted the same dissertation he had prepared for Leipzig, and had it promptly accepted.

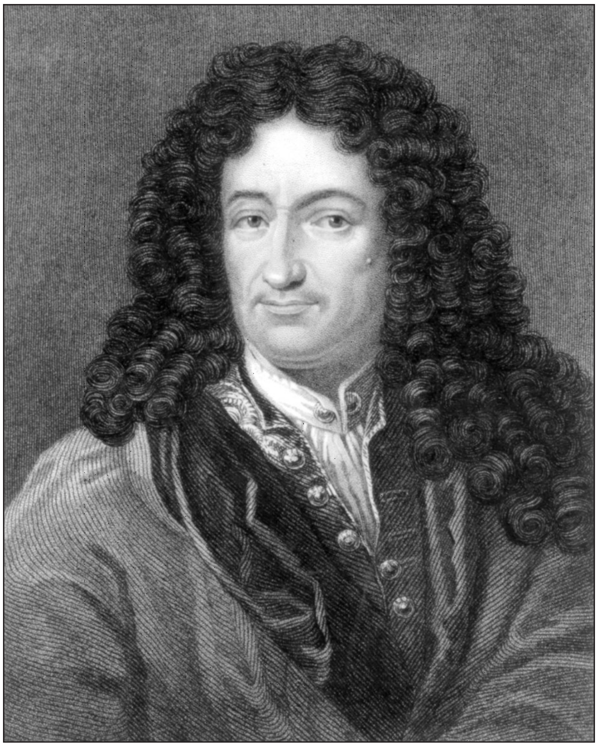
On receiving his degree, Leibniz was offered a position at Nuremberg in the law faculty, but he turned it down, perhaps out of dissatisfaction with the academic life brought on by the rejection at Leipzig. Instead, he took advantage of the interest displayed in his career by Baron Johann Christian von Boineburg to obtain a position as a judge in Mainz in 1671. He saw a future in the scholarly world ahead of him and found that the support of the elector of Mainz would enable him to travel and pursue his research throughout Europe.

LIFE'S WORK

In 1672, Leibniz traveled to Paris, ostensibly to take part in diplomatic negotiations related to the conflicts between the Netherlands and France and England. In fact, however, Leibniz used his visit to Paris, which continued until 1676, to make the acquaintance of some of the leading scientists of the time. He learned of the machine for doing arithmetic that had been designed by the French mathematician Blaise Pascal and decided to improve on it. While Pascal's machine had done addition and subtraction, Leibniz designed a machine to handle multiplication and division as well. Although the machine was not built as rapidly as Leibniz had hoped, he was able to display a model of the machine in Paris and in London.

On Leibniz's return from London to Paris, he found it necessary to catch up with the state of mathematics. One particular area in which he made rapid progress was the use of techniques initiated by earlier French mathematicians like Pascal and Pierre de Fermat to calculate the areas under curves and to determine the slopes (rates of change) at points on curves. Up until the seventeenth century, questions about curves were investigated using the geometry of Euclid, which was already two thousand years old. By Leibniz's time, algebra had developed to the point that it could be used to replace a strictly geometrical approach to curves. Leibniz was able to use his algebraic expertise to arrive at a new branch of mathematics, called the calculus, putting calculations within reach of a wider audience.

In the decade before Leibniz's invention of the calculus, Sir Isaac Newton had come up with some of the fundamental ideas from which the calculus sprang. Newton himself was disinclined to publish his work until it was fully developed, and in the meantime he had had correspondence with Leibniz about his ideas. The appearance of Leibniz's preliminary work on the calculus created the origins of an argument about priority that stretched on for many decades. While Newton and Leibniz did not start with any personal animosity, both of them had devotees who felt that the issue of the invention of the calculus was a matter of national pride. The resulting schism in the mathematical world (generally between England and the rest of Europe) did not work for the betterment of mathematics on either side of the English Channel.



Gottfried Wilhelm Leibniz. (Library of Congress)

While Newton certainly developed his calculus before Leibniz, the latter had a notation that was more widely useful and more suggestive. This was part of Leibniz's general approach to science and logic. His hope, expressed often in unpublished fragments, was to create a universal language that would enable all human beings to understand one another. Once that language was in place, he felt that one could create a machinery for judging whether an argument was correct. As a result, he thought that wars could become a thing of the past and that disputes would be settled by calculation. The bitterness of the Thirty Years' War in Germany, which lasted into Leibniz's life, may have made this prospect especially appealing.

Leibniz was also interested in trying to extend the audience for his own philosophy by investigating cultures as remote as the Chinese. He tried to link his logic, his metaphysics, and his physics into a connected chain of reasoning, and he argued that the combination bore a resemblance to Chinese science and philosophy. For example, he saw binary arithmetic as part of Chinese culture. Many of these ideas were expressed in correspondence, which ran to many thousands of pages. While he also took advantage of the scientific journals that had only recently started to appear, the vast bulk of his work remained unpublished.

In the course of his intellectual adventuring, Leibniz also had to earn a living. After the death of the elector of Mainz, Leibniz passed into the service of the government in Hanover, to which he made contributions from economics to genealogy. He had hoped to find permanent employment in Paris after his years there, but he ended up having to return to Hanover. One of the tasks with which he was saddled was writing a history of the ruling house of Hanover, and he used that project to take him into southern Europe. His researches confirmed the hopes of his employer to find himself related to other royal houses in Europe, but this was not the work closest to Leibniz's heart.

In 1714, the elector of Hanover ascended the throne of England as George I. This political promotion did not have the effect on Leibniz's career for which he had hoped. While the monarch went to London, Leibniz was left behind in Hanover, partly because of his being seen as a remnant from an older era, partly because of the animosity with Newton, who was the most visible figure in British science at the time. Leibniz died two years later, neglected even in Hanover.

LEIBNIZ'S CALCULATOR

Gottfried Wilhelm Leibniz was struck as a scientist by the amount of time that astronomers and others had to spend carrying out calculations. He had also learned of the calculating machine designed by Blaise Pascal earlier in the century that could carry out addition and subtraction. The Englishman Samuel Morland had built a calculator that could carry out multiplication and division by means of a form of logarithms (which reduce multiplication to addition). While Morland's machine could multiply two numbers together, the answer was only approximate. Leibniz decided to include multiplication and division as operations, but to provide exact answers instead. He also hoped that the machine would be able to extract square roots.

In designing his machine, Leibniz used the same approach for addition and subtraction as Pascal had. Multiplication depended on a piece of equipment called Leibniz's stepped wheel. This really involved rods with teeth in them that interacted with other gears. Each of the stepped wheels had nine teeth of different length, the longest corresponding to the number nine and in decreasing order of size. If the number *A* is to be multiplied by the number *B*, the digits of *A* were entered into the machine via numbered dials, and then a metal peg was placed in a hole corresponding to the number *B*. The peg would then determine how fast the wheels turned (if *B* was four, they would be turning twice as fast as if *B* was two). The results were then transferred to the addition wheels, from which they could be read.

The machine could handle large numbers, but it was not completely automatic, as it required some intervention by the operator in carrying and borrowing. There was nothing faulty in the design of the machine, but the components had to be constructed to a degree of accuracy beyond what the machinists of the time could achieve. The surviving example in Hanover did not work, but there is a working model of the machine in the Science Museum in London. A variant of the machine was used by merchants over the next century, but the design appears to have had little influence on the efforts of Charles Babbage and the subsequent development of the computer in the twentieth century. It was Leibniz's vision of a machine to spare the need for human calculation that proved more influential than his construction.

IMPACT

At the time of his death, Leibniz's influence looked as though it was limited in science to the creation of the calculus. His calculating machine had not had any great success, although the manufacturer was able to keep producing copies for another century. Even in the area of mathematics, it might have seemed that his work was losing ground in popular esteem compared to Newton's.

As the eighteenth century continued, however, the advantages of Leibniz's notation were widely recognized in Europe, and not merely for political reasons. Leonhard Euler, the greatest mathematician of the time, followed Leibniz's conventions and extended the successes of the calculus in many directions. Perhaps the most decisive moment in determining Leibniz's legacy came in early nineteenth century England, when the generation of young mathematicians being educated at Cambridge University revolted against the Newtonian notation they were being taught and insisted on learning Leibniz's instead. This provided for a reunion of the world of calculus, and both sides were speaking the language of Leibniz.

One of the complaints early urged against the way Leibniz presented calculus was his use of infinitesimals. These seemed like murky sorts of numbers, not quite zero, but not quite ordinary positive numbers. Other means for establishing the foundations of calculus were developed in the nineteenth century, but in the twentieth century Abraham Robinson reintroduced infinitesimals as a way of explaining the basis of calculus. While Robinson's approach used many ideas that would have been unfamiliar to Leibniz, Robinson himself regarded his work as a vindication of Leibniz's ideas.

Leibniz's notion of a universal logic had little influence until his work was rediscovered at the beginning of the twentieth century. Then, mathematicians such as Bertrand Russell began to notice similarities between the development of mathematical logic and Leibniz's dream both of a universal language and of a mechanical way of carrying out reasoning. Just as Robinson's work on calculus could be seen as fulfilling Leibniz's vision in mathematics, so the creation of the modern computer gave physical form to what Leibniz had conceived three centuries earlier.

—*Thomas Drucker*

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See also: Charles Babbage; Sir Isaac Newton; Blaise Pascal.

EMMETT LEITH

American physicist and electrical engineer

Leith and Juris Upatnieks presented the first three-dimensional hologram at a conference in 1964. Holography has been applied in many fields, including data storage, credit card security, art, and interferometry.

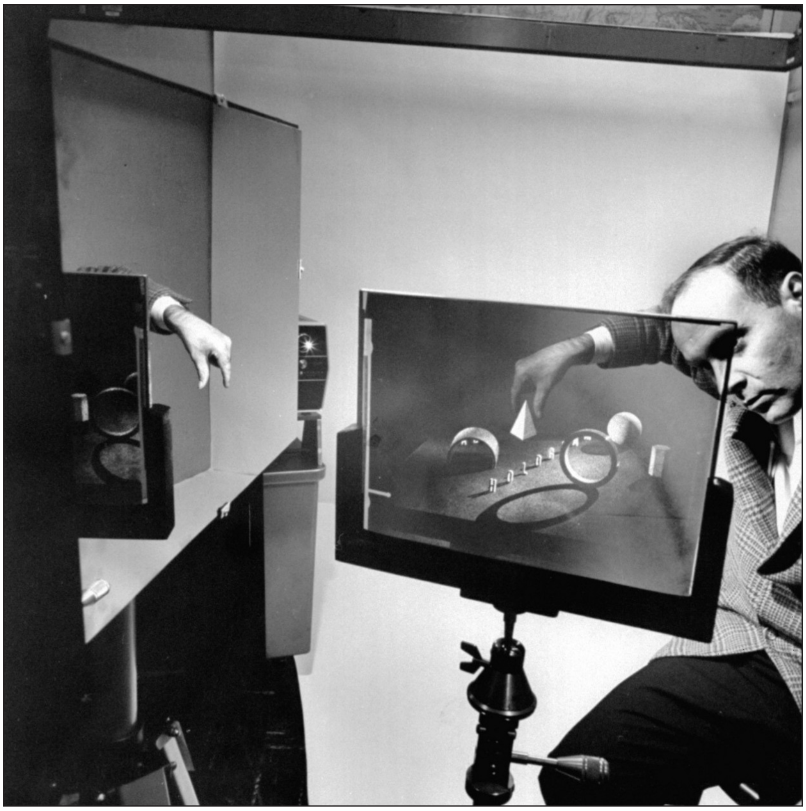
Born: March 12, 1927; Detroit, Michigan
Died: December 23, 2005; Ann Arbor, Michigan
Also known as: Emmett Norman Leith (full name)
Primary fields: Electronics and electrical engineering; optics; physics
Primary invention: Three-dimensional holography

EARLY LIFE

Emmett Norman Leith (leeth) was born on March 12, 1927, in Detroit, Michigan. Little is known about his childhood. He attended Wayne State University in Detroit, where he graduated with a bachelor of science degree in physics in 1949 and received his master of science degree in physics in 1952.

LIFE'S WORK

After finishing his master's degree, Leith took a job with the University of Michigan's Radar Laboratory, part of its Willow Run facilities. He worked for the university



Emmett Leith demonstrates holography. (Time & Life Pictures/Getty Images)

during his entire fifty-two-year career. The laboratory had an Army contract to develop synthetic aperture radar (SAR), a scanning radar system to be used by aircraft to create topographic maps. Many thought that the project for this high-quality imaging radar system would fail because airplanes could not carry the necessary massive antenna. With SAR, an aircraft could be outfitted with a five-foot antenna, which acted as a much larger one. The antenna would send out a signal that hit objects on the ground and bounced back. The data would then be captured as a line on photographic film, and the lines would produce images when a computer developed the film. The early computers of the early 1950's were not able to handle the volume of data needed for SAR. While other scientists worked on improving computer technology, Leith began working with physical optics solutions.

By 1957, Leith had created a new version of SAR based on his optics research. He later described the system as a "holographic viewpoint." At first, it seemed that Leith's method was valid only in theory; the first eight trials failed. The ninth test flight, however, produced startling results, successfully mapping the Michigan terrain. Leith's work with SAR eventually led to his research in holography. British scientist Dennis Gabor first introduced the idea of holograms in 1947. Gabor's holograms looked fuzzy and had double images, in part because he was working with a mercury lamp. He had hoped that his research would be used to improve the resolution of electron microscopes. By 1955, most scientists felt that holography could not be accomplished successfully and abandoned the field.

Leith began thinking about applying certain optics principles used in SAR to holography. In 1960, Leith told coworker Juris Upatnieks about his theory of how to build holograms. Leith planned to produce an unfocused image on a transparency and use the recorded image to get a clear picture. Upatnieks was not interested at first but was eventually convinced that Leith's idea might work. Leith and Upatnieks used a continuous-wave laser as their light source, a crucial device for creating clear holograms. Based on Gabor's theory, their method—called carrier-frequency, or off-axis, holography—split two beams of light from one coherent beam. One of the beams (the object beam) is shone onto the object to be recorded, and the other (the reference beam) is deflected by a mirror onto the photographic film behind the object. The object beam reflects off the object and converges with the reference beam on the photographic plate, resulting in a negative that looks like a random collection of blobs and specks. This "hodgepodge," as Leith called it, is actually the hologram.

A second step must be taken in order for the hologram to be viewable. In the reconstruction stage, the hologram is illuminated with a replica of the reference beam. The result is two separate images, a virtual one that appears behind the plate and a real one that appears in front of the plate. Together these two images form a hologram. In optics, a real image is produced when the rays of light exiting a lens actually converge at a point. This image can be produced on a screen, such as a movie screen. A virtual image is created when light rays shown through a lens only appear to intersect at a point. This image (such as a reflection seen in a mirror) cannot be produced on a screen.

The two men refined their method in 1961 and published their work in the journal of the *Optical Society of America* the following year. They had proven the critics wrong; holography was possible. In 1963, their work was known as lensless photography, simply because no lens was used. Having successfully found a way to make holograms of any object, Leith and Upatnieks began working on further refining their method. The next goal was to create a three-dimensional (3-D) hologram. In 1964, they presented a paper at an Optical Society of America conference, having successfully created the world's first 3-D hologram. Again, their success was due in part to the newly developed laser, which allowed them to use coherent light to make the hologram three-dimensional. When the two scientists showed their colleagues a hologram of a toy train, the image appeared so real that many of the men thought it was a trick done with mirrors. Leith told *Michigan Engineer* magazine that a few of the scientists even had asked him where the train was. He told them it was back in Ann Arbor. Viewing the hologram was like seeing the toy train in person. It was even possible to look behind the train.

Leith and Upatnieks filed for the first holography patent on April 23, 1964. It was titled "Wavefront Reconstruction Using a Coherent Reference Beam." The term "wavefront reconstruction" had been Gabor's initial name for holography. Leith eventually held more than fourteen patents. During the 1960's, he also played a major role in setting up an optics program for the University of Michigan Physics Department.

The toy train hologram created a lot of buzz within the optics community. News of it spread to nonscientists around the world through press releases, newspapers, and magazines. *Life* magazine covered the story of Leith and the hologram; articles in *Scientific American*, naturally, focused on the science. Holography became a popular field of study for scientists around the world. By 1970, hundreds were working on improving techniques, materials, and applications. Many of these researchers were not optical scientists. Applications for holograms in medical imaging, data storage, and entertainment were being investigated.

In 1978, Leith received his Ph.D. in electrical engineering from Wayne State University. The following year, he was given the National Medal of Science by President Jimmy Carter for his work in holography. Over the course of his career, Leith received several other commendations, including (with Upatnieks) the Inventor of the Year Award (1976).

Leith continued to teach physics, optics, and computer science at the University of Michigan until his death in 2005. He also continued his research in optics and imaging. He suffered a stroke on December 22,

HOLOGRAPHY

Hungarian-born electrical engineer Dennis Gabor invented the field of holography in 1947. He was working at a British medical company while working to improve the resolution of electron microscopes. He theorized the need for a strong beam of light having a single color and wavelength. Laser technology, instrumental in Emmett Leith and Juris Upatnieks's success, was not invented until 1960. Gabor did his work with a mercury lamp, resulting in holograms that looked fuzzy. In 1971, Gabor won the Nobel Prize in Physics for his research in holography. The Nobel Committee cited the work of Leith and Upatnieks as support for the importance of his theories. Gabor even mentioned Leith and the SAR holography work during his Nobel lecture.

Russian scientist Yuri Denisyuk produced the first hologram of a three-dimensional object (the hologram itself, however, did not appear three-dimensional) in 1962. One of the common types of holograms is known as the Denisyuk (or reflection) hologram, which is multicolored and uses only a white light reference beam. Leith and Upatnieks's version is known as a transmission hologram. In 1968, Stephen A. Benton invented the rainbow hologram, which is now used as a security feature on credit cards. The rainbow coloring is produced from a white light source instead of a laser.

Holography is also used for data storage (for instance, in Blu-ray discs). In addition to credit cards, holograms are used to secure books, digital video discs (DVDs), and other products. Since holograms are difficult to counterfeit, many countries have put them on their paper currency.

Holography has also had an impact on art and entertainment. The first art show using this technology was held by the Cranbrook Academy of Art in Michigan in 1968. Salvador Dalí was the first artist to use the new art form, at his 1972 New York exhibit. During the 1970's, several art schools were created whose focus was holographic art. None of these remains open. The Massachusetts Institute of Technology Museum has a large collection of holograms and related art.

2005, and died the following day from an internal hemorrhage. Leith was to retire on December 31. He was survived by June, his wife of forty-nine years, and two daughters and three grandchildren.

IMPACT

Leith's work in optics and holography has had great influence. His early work on the SAR program for the Army helped create a radar system capable of producing high-quality maps of enemy terrain from a safe distance. His work on SAR piqued his interest in optics, which started his career in holography.

Much of his later work dealt with biomedical imaging. Leith and one of his former graduate students, Dr. David Dilworth, collaborated from 1987 to 2005 to create improved biomedical imaging. Together they held a patent related to methods of early detection for breast cancer.

Photon migration, or imaging through human tissue, has become a whole new field of optics. Leith is among the field's pioneers, becoming involved in the research in the late 1980's. His goal was to make human tissue transparent, allowing doctors to look through the tissue to spot tumors. In the 1990's, Leith began working on a joint project with the Michigan Center for Biological Information and the University of Michigan that aimed to produce a virtual 3-D human, visible without 3-D glasses. The image would be used for education, dissections, and virtual surgery.

Leith also influenced a number of students, many of whom pursued fields dealing with optics or holography. Leith was influential in creating the University of Michigan's optics program. His Friday lectures were always filled with demonstrations. Students found themselves drawn in by Leith's enthusiasm for optics.

—Jennifer L. Campbell

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See also: Dennis Gabor; Gordon Gould; Ali Javan; Gabriel Lippmann.

JEROME H. LEMELSON

American engineer

The holder of more than five hundred patents, Lemelson is second only to Thomas Alva Edison as the most prolific American inventor. Lemelson was frequently in conflict with corporations that wanted to avoid crediting him for his inventions, which included components for a host of devices ranging from ATMs to videocassette recorders.

Born: July 18, 1923; Staten Island, New York
Died: October 1, 1997; Incline Village, Nevada
Also known as: Jerome Hal Lemelson (full name)
Primary fields: Computer science; electronics and electrical engineering; household products; manufacturing
Primary invention: Machine vision

EARLY LIFE

Jerome Hal Lemelson was born on July 18, 1923, on Staten Island, New York, the oldest of three boys. His father was a medical doctor who studied at Columbia University and worked out of his home. His mother was a schoolteacher trained at the normal school in Trenton, New Jersey.

Lemelson and his younger brothers first attended a small two-room school in which his mother had once taught and later attended public schools on Staten Island. He was fascinated by all things mechanical and was interested in inventing at an early age. As a teenager, he invented a lighted tongue depressor for his father. Lemelson attended New York University (NYU) but left before finishing to join the military in World War II. His engineering skills led to his assignment in the engineering department of the Army Air Corps. After serving in Alaska, he was transferred to Louisiana to teach auto mechanics to African American troops.

After military service, Lemelson returned to NYU, where he made up for lost time participating in a number of joint programs. He graduated in 1951 with a bachelor's degree in aeronautical engineering and two master's degrees, one in aeronautical engineering and the other in industrial engineering. While still in graduate school, Lemelson was employed by the Office of Naval Research to develop pulse jets and rocket engines.

LIFE'S WORK

After graduating from NYU, Lemelson was hired by Republic Aviation in New York, where he designed guided missiles. At the time, he was sharing a small apartment with one of his brothers (also an engineer). Lemelson would fill notebooks with his inventive ideas and have his brother sign and date the notes after reading them, a step Lemelson recognized as essential to supporting future patent application claims.

In 1951, Lemelson witnessed the operation of an automatic metal lathe controlled by a punch-card system at a New York factory, inspiring him to create his most important invention: a universal robot that utilized "machine vision" to perform a number of actions, including moving and measuring products and inspecting them for quality control. The machine took him years to build. Between 1951 and 1954, Lemelson wrote patent applications for a flexible manufacturing system, an automated warehousing system, and a number of other inventions for industrial automation. He wrote all these patent applications based on his own legal and industrial research since he could not afford an attorney.

Lemelson also invented toys. He found that toy companies were more inclined to license his ideas and inventions because the companies needed a tremendous number of new products to meet the demands of a growing market. They also found it difficult to maintain their own research and development departments during the 1950's. Lemelson patented a form of a toy cap, a propeller beanie, in October, 1953, and licensed a wheeled toy to the Ideal Toy Company.

The first of Lemelson's many patent infringement cases involved his idea for a cutout face mask that could be printed on a cereal box. He had filed a patent and then presented his idea to a cereal company, which turned Lemelson down but three years later began printing the face masks on its cereal boxes. When he saw that his idea had been stolen, he sued, but the lawsuit was dismissed in district court and on appeal. The cereal company spent upwards of $150,000 on legal fees, whereas licensing fees would have cost about one-tenth that amount. During his career, he was involved in more than twenty patent infringement cases, most of which he lost.

Lemelson was a "workaholic." Even on his return from his honeymoon in the Bahamas in 1954, Lemelson stopped at the U.S. Patent Office to do research. It was a stiflingly hot and muggy summer day in Washington, D.C. A chance comment overheard by Lemelson's new wife, Dorothy, led to an idea for a video-filing system using spools of magnetic tape (later called videotape) to re-

MACHINE VISION

Jerome H. Lemelson said that his machine-vision technology was the invention of which he was most proud. He began thinking about the concept as early as 1951, the year he graduated from New York University. He was working for Republic Aviation and had the opportunity to visit the Arma factory in Brooklyn. There he observed an automatic metal lathe controlled by a punch-card system, inspiring him to create a revolutionary new industrial procedure.

Lemelson began thinking about inventing a universal robot that could perform multiple functions, such as welding, riveting, transporting, and inspecting for quality control. This robotic system depended on machine-vision technology. With machine vision, a video camera took digital pictures that were analyzed by computers. Developing this invention required more than three years of work and a 150-page application, which he completed by Christmas Eve, 1954. A whole array of inventions—from automobile robotics to bar codes and automated teller machines (ATMs)—depend on Lemelson's basic machine-vision concept.

As difficult as the concept and technology were, the process of patenting the procedure and protecting the patent took years before Lemelson could realize any financial gain. While Lemelson had great difficulty in winning patent infringement lawsuits against U.S. corporations, he had greater success with foreign companies. Eventually, Lemelson won lawsuits against Honda, Toyota, Mazda, and Nissan for his machine-vision technology now used in their sophisticated robotics systems for manufacturing automobiles. This victory led other automakers in Europe and Asia to settle on generous terms without the excessive legal fees.

cord documents. The documents on the tape could be viewed on a television set with a mechanism to freeze frames. Lemelson created the machine to operate the tape, and this machine also became the basis for audio and videocassette recorders.

By the early 1960's, Lemelson had quit his engineering job in order to concentrate solely on his inventions and patent applications. During this period, he invented machines for injection molding, fax transmission, and a target game using Velcro-coated Ping-Pong balls. The cost of the patent applications and legal fees consumed so much of his income that the family was dependent on his wife's income to pay the bills.

In the late 1960's, Lemelson established the Licensing Management Corporation to market his and others' inventions. Prominent among his clients were those seeking to market technologies based on the National Aeronautics and Space Administration (NASA) space program, but opposition from large corporations reduced the profits substantially. This and a few other licensing companies Lemelson created were not very successful at this time. Lemelson had greater success in both licensing and patent infringement cases if the corporations involved were foreign. He successfully licensed his audiocassette-drive mechanism to the Sony Corporation for use in its Walkman (released in 1979).

Lemelson continued to invent until his death from cancer on October 1, 1997. He filed forty patent applications that year. Perhaps it is not surprising that these were for medical devices, as his mind was focused on ways that his own cancer might have been cured. Lemelson died in Incline Village, Nevada, at the age of seventy-four.

IMPACT

Lemelson invented and patented more than five hundred devices and processes during his lifetime, including toys, computer equipment, photographic storage devices, bar-code technology, an audiocassette-drive mechanism, operational systems for tape and cassette recorders, and a host of other inventions. His machine-vision technology had particularly wide-ranging applications; much of it stimulated other related inventions. Perhaps most important, throughout his life he defended the rights of independent inventors such as himself to be a part of the innovation and entrepreneurship necessary to advance the American economy.

Lemelson was criticized and opposed by major corporations, who had an interest in confining all innovation to their own research and development departments to avoid paying licensing fees. In Lemelson's case, they were sometimes willing to spend more on legal fees than licensing fees simply to be able to drive independent inventors from the marketplace. Lemelson's success in patenting his inventions and defending those patents was an important service for independent inventors. In 1993, he and his wife established the Lemelson Foundation, which funds programs to promote independent inventors around the world.

—Richard L. Wilson

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See also: Thomas Alva Edison; Georges de Mestral; Don Wetzel.

ÉTIENNE LENOIR

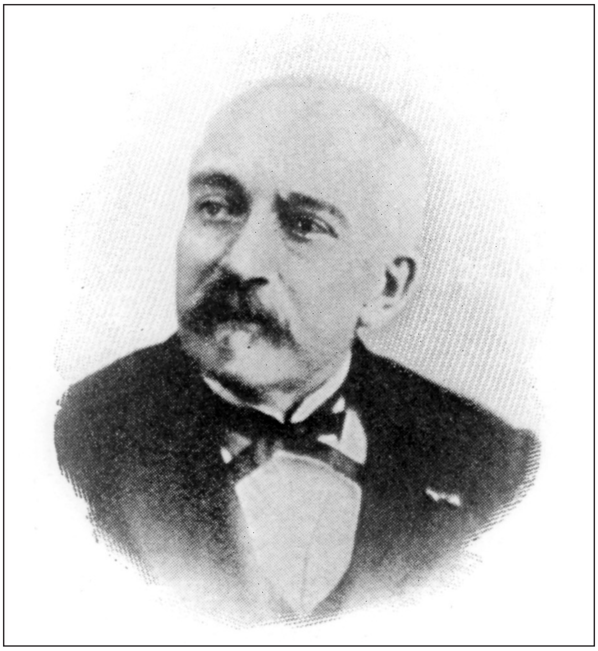
Belgian French electrical engineer

Lenoir invented the internal combustion engine and the spark plug. His engine led the way to motorized transportation and mechanized farming. The spark plug is still used in many engines today, including the gas-powered automobile.

Born: January 12, 1822; Mussy-la-Ville, Belgium
Died: August 4, 1900; La Varenne-Saint-Hilaire, France
Also known as: Jean-Joseph-Étienne Lenoir (full name)
Primary field: Mechanical engineering
Primary invention: Internal combustion engine

EARLY LIFE

Jean-Joseph-Étienne Lenoir (zhahn zhoh-ZEHF ay-TYEHN luh-NWAHR) was born in Mussy-la-Ville, Belgium, on January 12, 1822. Little is known about Lenoir's early life except that he taught himself chemistry. In the early 1850's, he moved to Paris to work as an enameller. There he became interested in electroplating. He devised



Étienne Lenoir. (Smithsonian Institution) a number of inventions, including a railway telegraph, a railway signaling system, and electric brakes, as well as the first parabolic mirror for use in lighthouses.

THE INTERNAL COMBUSTION ENGINE

Prior to Étienne Lenoir's work, inventors had concentrated on perfecting steam engines, which created pressure and heat outside of the cylinder. The heat then entered the cylinder and moved the piston. Several of these inventors had drawn diagrams of an engine within which the combustion would occur, but no internal combustion engine had actually been built. In 1858, Lenoir invented a two-stroke internal combustion engine that used an electric spark ignition and was fueled by illuminating gas (also known as coal gas). The engine was very similar to a double-acting steam engine; however, Lenoir had made important modifications to the engine, namely, having the combustion occur inside the engine.

Lenoir's internal combustion engine had stemmed valves through which a mixture of coal gas and air entered the engine. The mixture was drawn into the engine by the movement of a piston operated by a flywheel. Once the piston was partially drawn down in the cylinder, an electric spark ignited the gas and air mixture. The combustion then forced the piston the rest of the way down the cylinder. The flywheel then returned the piston to its original firing position. The valves that let the air into the cylinder also provided for the escape of the gas created by the explosion. The single-cylinder two-stroke engine fired on every revolution of the crankshaft. The engine was noisy and produced a considerable amount of pollutants. It was primarily useful for running pumps and small machines.

When Gottlieb Daimler, an inventor who played an instrumental role in later developments of the internal combustion engine, visited Lenoir's factory in Paris, he was not impressed by his engine. It was expensive to use and needed a very high temperature to function. However, Daimler later worked for the Gasmotorenfabrik Deutz, of which Nikolaus August Otto was part owner. It was Lenoir's engine that had inspired Otto to build a four-stroke internal combustion engine.

Lenoir continued to develop his internal combustion engine and successfully adapted it to run on a liquid fuel. This was the engine that he used to power his Hippomobile, a three-wheeled wagon with a passenger compartment and a separate compartment for the engine. He drove the vehicle from Paris to Joinville-le-Pont in a nine-mile trip that took three hours, making him the first to build a functioning vehicle powered by an internal combustion engine.

Lenoir also developed a stationary four-stroke internal combustion engine that he manufactured and sold for agricultural use. This engine was basically the same design as his original except that it produced power once every two revolutions of the crankshaft. Otto, Daimler, and others researched, adapted, and improved on the internal combustion engine to construct a reliable engine that could power an automobile.

LIFE'S WORK

In 1858, having studied the steam engines in use at the time, Lenoir began working on an engine that would produce its power from within. Lenoir envisioned an engine that would create its power by using a combustible gas mixture. In 1859, while he was working as a consulting engineer for Gauthier et Cie, he succeeded in building the first internal combustion engine. Lenoir's engine resembled a double-acting steam engine, but unlike the steam engine, it did not depend on an outside source for its power. It fired an uncompressed charge of air and illuminating (coal) gas with an electric spark ignition that he had designed. This type of ignition was unknown before Lenoir's invention of the spark plug, which is still in use today.

On January 24, 1860, Lenoir obtained a patent for his internal combustion engine. With a capital of two million francs, he established a company that he named Société des moteurs Lenoir. The company was housed in Paris on the Rue de la Roquette in the eleventh arrondissement. The engine that Lenoir built was relatively weak and fairly large in size. It required eighteen liters of the gas mixture to produce a horsepower rating of two. Although his engine had a number of drawbacks, it was very reliable and was particularly suited to run pumps and other small machinery. He succeeded in selling more than five hundred engines in France, Germany, and the United States during a five-year period. A considerable additional number of the engines were built and sold in Germany as a licensed product. By 1865, Reading Gas Works in London had begun producing the engines for Lenoir's company.

Lenoir hoped to use his internal combustion engine to power a vehicle. After making several improvements to his invention, including adding a carburetor and using petroleum for fuel, he attached his engine to a three-wheeled wagon. The vehicle was immediately brought to the attention of the public by *Le Monde Illustré*, a popular nineteenth century illustrated newsmagazine. *Le Monde Illustré* published a plate showing Lenoir's vehicle with a detailed description of how it worked. The writer of the article emphasized the fact that the vehicle was constructed such that the engine was in a separate compartment, leaving ample space for the passengers. He also noted the vehicle's gas reservoir. He described how the wheels were turned by a chain mechanism attached to cogwheels and how the steering mechanism worked, but he gave no details about the engine itself.

Lenoir did not actually make a trip in such a vehicle until 1863, when he drove from Paris to Joinville-le-Pont, a distance of about nine miles. It is not clear as to whether he used the vehicle illustrated in *Le Monde Illustré* or another somewhat improved version. His heavy vehicle, called a Hippomobile, was powered by a 1.5-horsepower engine adapted to run on liquid fuel. The vehicle used a considerable quantity of fuel and was able to attain only a speed of three miles per hour. He experienced several breakdowns and other problems on his journey. The engine not only was fuel inefficient and noisy but also overheated easily and seized up unless a large quantity of cooling water was added to it. Still, the engine was given a good reception by the Paris press, especially by *Cosmos*, and in the United States by *Scientific American*, which repeated the pronouncement made by *Cosmos* that the steam engine had been replaced.

Although he had received a patent on the Hippomobile in 1863, Lenoir apparently did not believe that his vehicle had the potential to be either successful or profitable. He abandoned his work on the road vehicle and shortly thereafter modified his engine for use on boats. However, he kept the vehicle that he had built. That same year, he sold all of his patents except the vehicle patent to the Compagnie Parisienne du gaz (Parisian Gas Company). In 1864, Lenoir sold his vehicle to Czar Alexander II in Russia, where it subsequently disappeared. In 1906, documents verifying the sale and exportation of the vehicle were found in Paris, but the vehicle itself was not to be found anywhere in Russia.

In 1870, Lenoir was given French citizenship for his contributions during the Franco-Prussian War. From 1876 to 1881, Lenoir was involved in a company called Lenoir, Rouart et Mignon, which made a type of four-stroke motor for use in motorboats and in agriculture. Lenoir continued to improve his engine for motorboats. In 1888, he designed a four-stroke boat engine that ran on naphtha fuel. In 1881, Lenoir received the Legion of Honor, awarded for his inventions in telegraphy. Although Lenoir's engine had been commercially successful, he lived in poverty during the last years of his life. He died at La Varenne-Saint-Hilaire on August 4, 1900.

IMPACT

Lenoir was the first to build an internal combustion engine and to commercially produce the engine. His engine so impressed the German inventor Nikolaus August Otto that Otto did further research and eventually built a four-stroke internal combustion engine that ran on liquid fuel. Otto's engine became the standard engine for all liquid-fueled automobiles. Lenoir made another extremely important contribution to the automobile with his invention of the spark plug, which remains an essential component of the automobile to this day. The Lenoir cycle used to model a pulse jet engine is an idealized thermodynamic cycle based on the operation of the internal combustion engine patented by Lenoir in 1860.

Lenoir's internal combustion engine had a significant impact on agriculture. His four-stroke engine was used to power farm machinery at the end of the nineteenth century. It also provided the basic design for internal combustion engines with improved efficiency, as mechanized agriculture became increasingly important during the twentieth century.

Several of Lenoir's inventions, including the railway signaling system, electric brakes, and parabolic mirror for lighthouses, significantly increased the safety of transportation and travel. His invention of the railway telegraph improved communication.

—*Shawncey Webb*

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Henry Ford; Nikolaus August Otto; Nikola Tesla.

LOUIS-SÉBASTIEN LENORMAND

French aeronautical engineer

Lenormand is credited with making the first successful parachute descent. He brought the parachute principle to the attention of inventors and is also credited with coining the term "parachute." His extensive research, teaching, and publication in the field of parachuting contributed to its acceptance as an important area of study and invention.

Born: 1757; Montpellier, France
Died: 1837; Castres, France
Primary field: Physics
Primary invention: Parachutes

EARLY LIFE

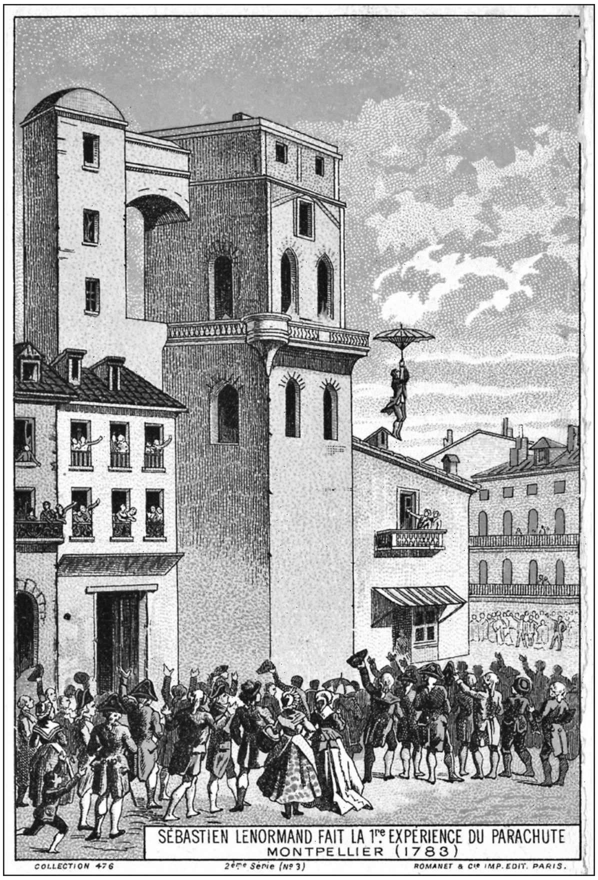
Louis-Sébastien Lenormand (lwee seh-bahs-TYAN leh-nohr-MAHN) was born in Montpellier, France, the son of a clockmaker. He studied chemistry and physics with Antoine Lavoisier and Claude Louis Berthollet in Paris. For a time, he was employed with the administration in charge of saltpeter. In this position, he learned how to make products such as gunpowder.

Lenormand left Paris after a time and returned to his native Montpellier, where he worked in his father's clock shop. During this period of his life, he became actively involved in the intellectual life of Montpellier. Inspired by the performance of a Thai equilibrist and the way in which the man used an umbrella to maintain his balance, Lenormand began conducting experiments in controlled descent, what is today known as parachuting. Before making his own parachute attempts, Lenormand tested his devices using animals. He employed umbrellas or devices based on umbrellas in these experiments.

LIFE'S WORK

In his first parachute attempt, Lenormand jumped from a tree; he used two modified umbrellas to control descent. He continued to refine his device and eventually constructed a fourteen-foot-diameter parachute still modeled on the umbrella but with a rigid wooden frame. On December 26, 1783, using this parachute, he jumped from the observatory tower in Montpellier. His safe descent was witnessed by a relatively large crowd of spectators, among whom were other inventors, including Joseph-Michel Montgolfier, who invented the hot-air balloon with his brother Jacques-Étienne that same year. Somewhat curiously, even though he made a successful descent, this concluded Lenormand's interest in parachuting.

Subsequently, Lenormand became interested in what he referred to as the science of "pure technology." He


SÉBASTIEN LENORMAND FAIT LA 1re EXPÉRIENCE DU PARACHUTE
MONTPELLIER (1783)
COLLECTION 476
2ème Série (N° 3)
ROMANET & Cie IMP. EDIT. PARIS.

Louis-Sébastien Lenormand parachutes from the observation tower in Montpellier, France, in 1783. Illustration from the late nineteenth century. (Library of Congress)

PARACHUTES

The concept of controlled descent can be traced to the ninth century. In Córdoba, Spain, ʿAbbas ibn Firnas developed what might be considered a primitive parachute. Wearing a large cloak resembling wings, he launched himself from a steep natural promontory outside Córdoba. The flight ended with a crash. A conical device resembling a parachute appeared in an Italian manuscript in 1470. Between 1480 and 1483, Leonardo da Vinci sketched a parachute-like device. Leonardo's design used a pyramid of wooden poles that held open a sealed linen cloth measuring twelve yards in height and twelve yards on each side. Leonardo left his device in the realm of ideas, however. More than a century later, the Croatian inventor Faust Vrančić sketched a parachute design that was simpler and more practical than Leonardo's.

By the eighteenth century, inventors had become interested in the parachute as a means to save lives. Louis-Sébastien Lenormand was one of these inventors, intending that his device be used to help people escape from a burning building. He constructed a device resembling a fourteen-foot-diameter umbrella but with a rigid frame. In 1783, he made a successful jump from the observatory tower in Montpellier, France. Although he was not the first to envision the parachute, he is credited as the inventor of the first useful parachute.

In 1793, Jean-Pierre Blanchard invented the first foldable parachute made from silk, lighter in weight and more manageable than linen. André-Jacques Garnerin improved the parachute by venting it (cutting a small opening at the apex of the parachute) to reduce oscillations during descent.

During the nineteenth century, parachutes became associated with carnival acts. Daredevils made astounding jumps from hot-air balloons using parachutes attached to the balloon's equator. When the performer jumped, the parachute broke loose. These feats fascinated spectators until Robert Cocking, using an inverted cone-shaped parachute, plunged to his death in 1837. Horrified, the public lost interest in these performances.

Nevertheless, inventors continued experiments with parachutes. In 1887, Captain Thomas Baldwin invented the parachute harness. In 1890, Paul Letteman and Kathchen Paulus invented the method of packing the parachute in a backpack. Paulus also created the intentional breakaway. With the invention of the airplane, parachutes became more important. The first jumps from an airplane were made in 1911; the first freefall jump in 1918. From World War I to the 1930's, the round solid cloth parachute remained the standard type.

During World War II, different types of parachutes—including the ribbon, ring-slot, and ring-sail parachutes—were designed to meet various military needs. The basic design of the parachute uses a lightweight fabric. Support tapes and suspension lines pass through cloth or metal connectors and are connected to risers (straps), connected to the harness. Military needs have brought about the development of cruciform (square), annular, and pull-down apex parachutes. The modern ram-air (self-inflating) parachute is made of two layers of fabric with air cells between them. All these designs are geared to improve descent control and safety.

Parachutes have been used as a means to deploy troops and to deliver supplies and equipment to soldiers. Parachutes are also used to deliver aid to disaster victims. Starting in the 1960's, parachuting became a recreational sport, known as skydiving.

found a monastery in Saïx, near Castres, where the monks were willing to afford him the opportunity to continue his technological research. Thus, he became a Carthusian monk and joined the brothers. Unfortunately, the French Revolution and its attack on monasticism severely interrupted Lenormand's idyllic life of research. In order to preserve his life, he had to renounce his vows and leave the Church. He married and moved to Albi, where he taught the new science of technology at a college that his father-in-law had established.

In 1803, Lenormand moved once again, this time to Paris. He found a position in the finance ministry working in the excise office. During his free time, he continued his research and experiments in technology. He also started publishing articles in technological journals. He applied for patents for a number of his inventions, including a paddleboat and a lighting system. In addition, he applied for a patent for a clock that was installed at the Paris Opera. This clock was very successful.

In 1815, Lenormand lost his position in the excise office. During the next fifteen years, he spent a vast amount of his time researching, experimenting, and publishing journals and a variety of technical manuals. He founded two very successful journals: *Annales de l'industrie nationale et étrangère* and *Mercure technologique*. He also published a twenty-volume dictionary between 1822 to 1835, appropriately called *Dictionnaire technologique: Ou, Nouveau Dictionnaire universel des arts* *et métiers*. It was a collaborative undertaking with Louis-Benjamin Francoeur, but Lenormand wrote most of the articles. The massive work was the physical manifestation of the academic discipline that he had introduced into the university system.

Lenormand envisioned his dictionary as the compilation of a complete course of study in technology. His intent was to offer a clear and accurate description of every aspect of human industry: agriculture, commerce, manufacturing, and the arts and crafts. He added a five-part classification to this compilation composed of four distinct categories of industrial arts—agriculture, mechanical arts, physical arts, chemical arts—and a fifth category on "pure technology." Lenormand placed in this category the activities usually referred to as the arts and crafts.

In 1830, Lenormand left Paris and returned to Castres. He became estranged from his wife and broke all ties with her family. He then renounced his marriage and returned to the monastery at Saïx. He once again took up his religious life. He died at Castres in 1837.

IMPACT

Although the parachute was not invented by Lenormand, he reintroduced and demonstrated the principle of the parachute. His interest in the device waned after his successful jump from the observation tower in Montpellier, but other inventors carried on what he had begun. Jean-Pierre Blanchard eliminated the rigid frame used by Lenormand and invented the first foldable parachute, which was made from silk. Blanchard claimed to have used a parachute to jump from a hot-air balloon in 1793; however, there were no witnesses to this event. It is André-Jacques Garnerin who is credited with the first jump using a nonrigid parachute. On October 22, 1797, he jumped from a hot-air balloon. Garnerin made several subsequent jumps from hot-air balloons at various altitudes.

Lenormand helped to create the academic discipline of industrial arts. He was also instrumental in popularizing technology. His journals, articles, and especially his *Dictionnaire technologique* made the processes of technology understandable to a wide audience. *Dictionnaire technologique* carried on the work of Denis Diderot and Jean le Rond d'Alembert, mid-eighteenth century philosophers who had placed the "mechanical arts" on a level equal with artistic, literary, and philosophical creativity in their *Encyclopédie: Ou, Dictionnaire raisonné des sciences, des arts, et des métiers* (1751-1772).

—*Shawncey Webb*

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See also: ʿAbbas ibn Firnas; George Cayley; Leonardo da Vinci; Joseph-Michel and Jacques-Étienne Montgolfier; Faust Vrančić.

LEONARDO DA VINCI

Italian engineer and artist

The archetypal Renaissance man, Leonardo da Vinci pursued interests in art, architecture, mathematics, astronomy, anatomy, biology, botany, philosophy, science, and engineering. In thousands of pages of detailed notes and drawings, which included hundreds of inventions, Leonardo examined the physical world around him, leading the world away from the superstitions of the Middle Ages and into the modern era of science and reason.

Born: April 15, 1452; Vinci, Republic of Florence (now in Italy)
Died: May 2, 1519; Cloux (now Clos-Lucé), near Amboise, France
Also known as: Leonardo di ser Piero da Vinci (full name)
Primary fields: Aeronautics and aerospace technology; civil engineering; military technology and weaponry
Primary inventions: Designs for making ropes, lifting columns, threading screws, spinning and weaving machines, flying machines, weaponry, boats, and many other devices

EARLY LIFE

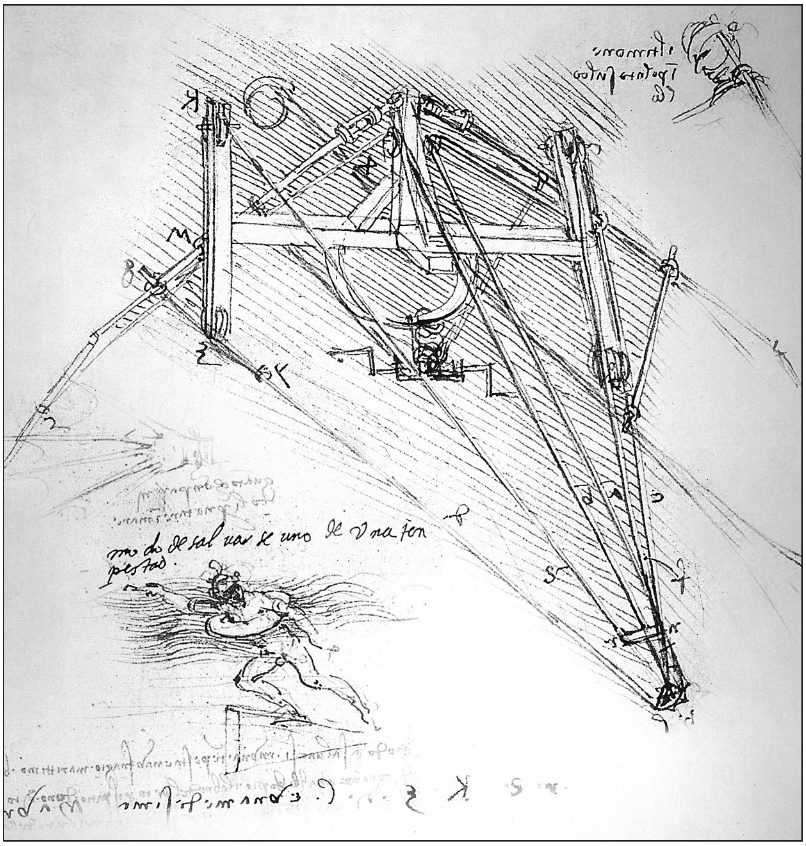
Leonardo da Vinci (lee-uh-NAHR-doh dah VIHN-chee) was born on April 15, 1452, in Vinci, a small town located in the hills above the lower Arno River Valley in the vicinity of Florence. Because he was the illegitimate son of a wealthy notary, Ser Piero, and a local peasant girl, Caterina, few records exist to document Leonardo's early years. In an era in which surnames were not yet in common use, Leonardo's birth name was Leonardo di ser Piero da Vinci, which meant "Leonardo, son of [Mes]ser Piero from Vinci," later shortened to Leonardo da Vinci, or Leonardo from Vinci. Leonardo apparently spent his first five years in Anchiano, a small village just outside Vinci, in the care of his mother, who may have been the first to introduce the young Leonardo to the beauty of the Tuscan countryside and to lay the groundwork for his later insatiable desire to understand the wonders of the natural world.

When Leonardo was age five, Ser Piero brought the boy to live with him and his family in Vinci, where Leonardo was groomed to follow in his father's occupation as a notary. Before long, however, Leonardo's artistic talents were recognized as too impressive to be ignored, and Ser Piero took his son to Florence, the hub of fifteenth century cultural and political activity. In 1466, Ser Piero secured for Leonardo the position of apprentice in the workshop of Verrocchio, one of the foremost artists of the day. There, the young Leonardo met not only important civic leaders and patrons but also other young apprentices such as Perugino, Ghirlandaio, and Botticelli, who, along with Leonardo, would later become some of the greatest artists of their era. In this invigorating atmosphere, Leonardo learned skills that would serve him as an artist and as an inventor and engineer as well, skills such as the vital role of keen observation, the importance of rational investigation, and the need for careful documentation. In 1472, when he was twenty, Leonardo was admitted into the Guild of St. Luke, the organization that oversaw both artists and doctors of medicine, a fortuitous combination for a young man with Leonardo's extraordinary proclivities.

LIFE'S WORK

Upon becoming a master, Leonardo established his own workshop, where, in 1473, he created his earliest extant drawing, a view of his beloved Arno River Valley, drawn from a bird's-eye perspective, which reflected his lifelong interest in birds and flight. In 1482, on the advice of Lorenzo de' Medici, Leonardo traveled to Milan to visit the court of Ludovico Sforza, known as Ludovico il Moro. In a letter to Ludovico, Leonardo offered his services as a military engineer, listing the many warfare devices and military benefits he could proffer, including portable bridges, mortars, mines, guns, cannons, covered chariots, and catapults. At the end of the letter, almost as an afterthought, Leonardo mentioned that he could also serve Ludovico as an architect and painter. In an era of intense rivalry, both in cultural status and military prowess, Leonardo's claims appealed to Ludovico, who wisely hired the prodigious young man. Leonardo remained in the Ludovico court from 1482 to 1499, during which time Leonardo worked intensely on mechanisms for both defensive and offensive military purposes.

Whether it was out of his own innate interests or because of the necessity of defending his homeland, Leonardo was always clearly involved in developing machines for warfare. Among his drawings, Leonardo included sketches for both a single sling and a double sling to hurl stones, as well as a giant crossbow. Leonardo also drew designs for a scything wagon, which, when pulled



Leonardo's sketch of an ornithopter with a pilot and a life preserver. (The Granger Collection, New York)

by horses, moves a system of gears that spin huge scythes protruding from the side of the wagon, capable of cutting down anything in their path. Leonardo missed no opportunity to enlarge and embellish upon current firearms. He multiplied the efficiency of the traditional single-barrel artillery by designing a three-barreled cannon, an eight-barrel machine gun, and even a thirty-three-barrel machine gun. Each of these guns was designed to be mounted on easily movable gun carriages that were adjustable both horizontally and vertically in relation to the desired target. In order to lift heavier artillery, Leonardo devised a winch in which the lifting and lowering was done with a worm screw and a spiral wheel. To improve the accuracy of his artillery, Leonardo explored the use of aerodynamic projectiles to control the trajectory of the ammunition. Concerned with the challenge of rapid ignition of the multiple artillery barrels he was designing, Leonardo drew plans for automated igniting devices and automatic strikers. The covered chariot that Leonardo had promised Ludovico Sforza in his letter of 1482 was, in essence, the forerunner of the modern tank. Leonardo proposed the construction of a round, metal-covered enclosure, which, when operated by eight men protected inside, could be turned and moved in any direction by men on the lower level, while men on the upper level of the machine fired through narrow openings in the top.

Leonardo was also interested in innovations at sea. He drew plans for fast boats that could ram and hold the enemy's craft while men protected by shields attacked the enemy with artillery. Leonardo also drew designs for paddle-propulsion boats, with the energy being provided by men in the hull, whose power was increased by a system of cogwheels and gears that multiplied the revolutions of the paddlers. He designed a ship with a double hull that would minimize the water intake if the ship's outer hull were damaged. In order to inflict as much damage as possible on an enemy vessel, Leonardo designed ship bottom breakers to facilitate the sinking of enemy ships. Leonardo was also concerned with spanning bodies of water. He designed fast construction bridges to enable armies to quickly build bridges with a system of wood logs and ropes. Leonardo also designed movable bridges, such as completely revolving bridges that could be turned in case of enemy advances; parabolic bridges, which, secured to one bank, could be turned on vertical hinges; and an impressive design for a single-span bridge with a double support that would permit the bridge to be of sufficient height to permit even vessels with tall masts to sail underneath. If a bridge was not available, Leonardo designed floats so that a man could simply walk across a body of water. Leonardo even drew plans for a diving suit that would allow a man to dive underwater and to breathe through a system of respiration pipes that reached the surface of the water.

The political and military events of the late fifteenth and early sixteenth centuries drove Leonardo from place to place. In 1499, Louis XII of France invaded Milan and defeated the ruling Sforza family. Leonardo was forced to flee to Venice, where he used his talents to invent devices to defend that city from attacks by sea. The next year found Leonardo back in Florence, where he rejoined his guild and resumed painting. During the ensuing years, Leonardo served as military engineer for Cesare Borgia, traveling between Italian cities devising defensive mechanisms and designing a functioning canal up to the Porto Cesenatico. Only after the Sforzas regained control of Milan in 1506 did Leonardo return once again to that city. In his later years, Leonardo lived and worked in Florence, Rome, and Bologna, making the acquaintance of his younger fellow artists, Michelangelo and Raphael. Leonardo spent his last years in France as the court engineer, architect, and painter to King Francis I. Throughout these tumultuous years, Leonardo recorded his observations, insights, and inventive devices in drawings and notations that filled thousands of notebook pages.

In addition to his copious studies on military matters, Leonardo also turned his attention to civil matters, with special attention to devising labor-saving devices and improving on existing work-related machines. Leonardo drew intricate plans for machines for making ropes, lifting columns, and threading screws. One of his particular interests was the fabrication of textiles, a major industry in Italy at the time. Leonardo drew designs for several spinning and weaving machines and included plans for an automated bobbin winder. He also devised teasing machines that processed cloth by running the cloth over a series of rollers. He designed a winged spindle that would stretch, twist, and wind thread simultaneously. Although most of the textile manufacture in Italy at the time was done with wool, silk was also a coveted material. Leonardo designed a silk-doubling machine that increased silk production output.

Leonardo was always fascinated by the possibility of locomotion, whether on land or in air. It is his experiments with flight for which Leonardo's inventive talents are perhaps best remembered. Leonardo seemed obsessed with enabling humans to fly like the birds. He drew many sketches of wings, both the natural wings of birds and human-made wings that were worked by various mechanisms. To assist the act of flight, Leonardo devised an inclinometer to control the horizontal positioning of the craft and anemometers to show the wind direction. Leonardo's dreams of flight ranged from designs for fly-

THE DREAM OF FLIGHT

To fly like a bird was a lifelong dream for Leonardo da Vinci. Leonardo said that he had a childhood memory of a bird flying down to his cradle and brushing its feathers against his face, and one of Leonardo's earliest drawings was an aerial bird's-eye view of the Arno River Valley. Throughout his life, Leonardo dedicated many in-depth studies to the flight of birds, such as his 1505 *Codex on the Flight of Birds*.

Leonardo's designs for a flying machine progressed over time. His earliest designs consisted of machines in which the human pilot, laying prone in a wooden frame, placed his feet in stirrups and moved his feet together, causing the downstroke of the wings; the pilot's hands directed the upstroke by means of a lever. Over time, Leonardo modified the movement of the pilot's legs, having the legs slide up and down, assisted by the hands, in order to make the wings beat. A still further advance was the addition of a head harness that manipulated a rudder to control direction. Leonardo drew numerous sketches of wing types, from a wing based on that of a bat to adjustable tilt wings, beating wings, and articulated wings, each in an effort to refine his flying machine. The most ambitious of his designs included a large enclosed cabin, capable of holding two pilots who operated the flapping bat wings with a complex system of screws and cranks.

As inspired as Leonardo's designs were for his early flying machines, two factors would have prevented his designs from ever taking off. First, the materials that were available at the time were just too heavy to be manipulated by even multiple human pilots. In addition, Leonardo's understanding of the flight of birds was fundamentally flawed. Leonardo believed that birds flew when the wing was moved down and back, as if the bird were swimming through the air like a swimmer through water. In actuality, the lift required for flight is created when birds move their wing feathers up and forward.

As time progressed, Leonardo replaced the flapping-wing designs with designs for fixed-wing glider crafts. At first, Leonardo did not provide a means for the pilot to control the machine through body movements. Eventually, however, he enabled the pilot to balance the craft by moving the body's extremities, effectively inventing a predecessor to the modern controlled glider.

Leonardo wrote a journal entry in which he stated that a great bird will take flight from Mount Cerceri, a mountain near Leonardo's residence at the time. Legends recount that one of Leonardo's assistants piloted the craft, crashed, and broke his leg. Whether one of Leonardo's great birds ever actually took flight will probably never be known. What is known is that in an era of holdovers of medieval traditionalism and superstition, Leonardo's dream of flight opened up a new vision of possibilities for the future.

ing machines, hang gliders, and parachutes to a complex rendering for an air screw, anticipating the future helicopter.

IMPACT

Leonardo was one of the foremost visionaries in history. In addition to creating such masterpieces as *The Last Supper* and *Mona Lisa*, Leonardo is credited with being one of the most prolific inventors of all time. His inventions were based on careful observation and copious documentation. Leonardo was unique for his time in that he explained not only the purpose of machines but also how machines actually worked. Leonardo was the first to conceive of machines as both a whole and a sum of its parts, realizing that the parts, such as flywheels, cogs, and gears, could be modified, improved upon, and utilized in innovative new ways. With this realization, Leonardo was able to combine individual parts into hundreds of new machines.

In his designs, Leonardo anticipated many modern inventions. He drew diagrams of a hydrometer that anticipated the modern science of hydraulics. His plans for devices for the canalization of rivers are still in use today. His designs for diving suits, parachutes, flying machines, and helicopters inspired generations of later inventors. In 1903, the Wright brothers achieved Leonardo's dream of heavier-than-air human flight. A few years later, the modern helicopter was developed. His plan for a single-span bridge, conceived in 1502 for the sultan of Istanbul but never realized because it was thought to be impossible, was brought to reality in 2001, when a smaller bridge based on Leonardo's design was constructed in Norway. On May 17, 2006, the Turkish government commenced construction of Leonardo's bridge over the Golden Horn at the mouth of the Bosporus, just as Leonardo had originally planned 504 years earlier.

Recognized now as some of the most farsighted inventions ever devised, Leonardo's achievements are displayed in museums around the world, chief among them the Leonardo da Vinci National Museum of Science and Technology in Milan, Italy, and the Leonardo da Vinci Museum at the Château du Clos Lucé in Amboise, France. His notebooks are the highlights of major collections in the Louvre, the National Library of Spain, the Ambrosian Library of Milan, and the British Library. Only one of Leonardo's notebooks is in a private collection: The Codex Leicester is owned by Bill Gates, an acclaimed inventor of the late twentieth century. Five centuries later, inventors can still draw inspiration from Leonardo da Vinci, the most prodigious of Renaissance men.

—*Sonia Sorrell*

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See also: ʿAbbas ibn Firnas; Aristotle; Roger Bacon; Giovanni Branca; George Cayley; Hero of Alexandria; Al-Jazarī; Louis-Sébastien Lenormand; Joseph-Michel and Jacques-Étienne Montgolfier; James Nasmyth; John Augustus Roebling; Igor Sikorsky; John Tyndall; Faust Vrančić; An Wang; Otto Wichterle; Wilbur and Orville Wright.

WILLARD F. LIBBY

American chemist

Libby, a chemist who specialized in the study of radioactive elements, developed the carbon-14 method used to determine the ages of archaeological artifacts. He also pioneered the use of radioactive elements to trace hydrological and geophysical processes.

Born: December 17, 1908; Grand Valley, Colorado
Died: September 8, 1980; Los Angeles, California
Also known as: Willard Frank Libby (full name)
Primary field: Chemistry
Primary invention: Carbon-14 dating

EARLY LIFE

Willard Frank Libby was born on a farm in Grand Valley, Colorado, on December 17, 1908. His parents, Ora Edward Libby and Eva May Libby, soon moved to California, where Libby attended grammar school in Sebastopol. There, he received his high school education at Analy High School, where he played on the football team. Libby entered the University of California, Berkeley, in 1927, where he was awarded a B.S. degree in chemistry in 1931. He received his Ph.D. in chemistry in 1933 and was appointed an instructor at the university's Department of Chemistry. Over the next decade, he was promoted to assistant professor and later to associate professor of chemistry. His major research during this period was focused on building sensitive Geiger counters, electronic devices that are used to measure the decay of natural and human-made radioactive elements.

Libby married Leonor Hickey in 1940. Together they had twin daughters, Janet and Susan, in 1945.

LIFE'S WORK

In 1941, Libby was awarded a Guggenheim Memorial Foundation fellowship to conduct research at Princeton University. However, the start of World War II interrupted his efforts. Shortly after the attack on Pearl Harbor on December 7, 1941, Libby joined the Division of War Research at Columbia University in New York. He worked on the Manhattan Project to develop the atomic bomb. At Columbia, Libby worked with Harold Urey, who won the Noble Prize in Chemistry in 1934 for isolating deuterium, a heavy isotope of hydrogen. Under Urey's direction, Libby was responsible for developing the gaseous diffusion technique to separate and enrich uranium 235, which was used in the atomic bomb dropped on Hiroshima.

In 1945, at the end of World War II, Libby was appointed professor of chemistry at the University of Chicago, where he worked in the university's Institute for Nuclear Studies. In 1946, Libby showed that when cosmic rays (charged particles moving through space at nearly the speed of light) strike the upper atmosphere of the Earth, they produce trace amounts of tritium, a rare radioactive isotope of hydrogen having an atomic mass of three units, and carbon 14, a rare radioactive isotope of carbon. This tritium can be incorporated into water that is present in the Earth's atmosphere. Since tritium has a half-life (the time required for half of the starting amount of an isotope to decay away) of only twelve years, it can be used to trace the presence of atmospheric water. If water has been isolated underground for many years, all the tritium that was added while the water was in contact with the atmosphere will have decayed. By measuring the tritium concentration, Libby developed a method to determine the last time atmospheric water was added to underground water, such as well water. He applied the same technique to measuring the circulation pattern and

Willard F. Libby. (©The Nobel Foundation)

Carbon-14 Dating

Carbon has two stable isotopes, carbon 12 and carbon 13. A small amount of carbon 14, a radioactive isotope of carbon, is also found on Earth. Since carbon 14 has a half-life of only 5,730 years, any carbon 14 present when the Earth formed has decayed away. However, cosmic rays interact with nitrogen in the Earth's atmosphere, producing carbon 14. If the number of cosmic rays is constant, the ratio of radioactive carbon 14 to stable carbon 12 stays at a constant value, with the production just balancing the decay. The carbon 14 reacts with oxygen in the atmosphere, forming carbon dioxide, which spreads around the world. Plants take in atmospheric carbon dioxide during photosynthesis, so, while plants are alive, their carbon 14-carbon 12 ratio is the same as the atmospheric ratio. Animals ingest carbon 14 by eating plants or other animals, so the carbon 14-carbon 12 ratio in living animals is also the same as the atmospheric ratio. However, as soon as the plant or animal dies, it stops taking in carbon dioxide, and the carbon 14 decays away. The carbon 14-carbon 12 ratio serves as a clock, ticking away the time since the organism died.

A fresh sample of carbon 14 produces about fourteen disintegrations per minute per gram of carbon. When the sample is isolated from new input of carbon 14, the number of disintegrations per minute per gram of carbon decreases exponentially. After 5,730 years, one-half of the original amount of carbon 14 remains, and the carbon-14 decay rate is only about seven disintegrations per minute per gram of carbon. After another 5,730 years, one-fourth of the original amount remains, and after another 5,730 years, only one-eighth of the original amount remains.

Carbon 14 decays by the emission of an electron, which can be detected with instruments such as proportional counters or scintillation counters, electronic devices that detect the individual decay products. However, the cosmic rays produce only a very small amount of carbon 14. In the Earth's atmosphere, there is only one carbon-14 atom for every trillion carbon-12 atoms, so these devices require a relatively large amount of carbon, typically about one gram, to measure a decay rate accurately.

The sensitivity of carbon-14 dating increased with the development of accelerator mass spectrometry. With this technique, the carbon is vaporized and separated into its isotopes, which are counted directly rather than by decay counting. This method allows dating of only a few milligrams of carbon. The carbon-14 dating technique provides reliable ages on samples dating back a few hundred years to about eighty thousand years.

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the mixing of water in the ocean, and to determining the age of wines.

In the same research paper that reported the tritium production, Libby noted that the radioactive carbon 14 produced by cosmic rays would be incorporated into living organisms. However, once an animal or plant dies, it takes in no more atmospheric carbon, so the ratio of carbon 14 to the stable carbon 12 decreases. By measuring this ratio, Libby suggested that he could determine how long ago the plant or animal had died. In 1947, Libby and Ernest Anderson performed an experiment demonstrating that Libby's idea was correct. They showed that the methane gas from Baltimore sewage had measurable carbon 14, while methane produced from old petroleum deposits (produced from organisms that lived millions of years ago) did not. In 1949, Libby and James Arnold, a research associate at the Institute for Nuclear Studies, demonstrated that the carbon-14 dating technique worked on archaeological samples: Their carbon-14 technique was as accurate as other dating methods used on objects such as wood from the coffin of an Egyptian mummy.

Libby used the radiocarbon dating technique to determine the ages of linen wrappings from the Dead Sea scrolls, bread from the village of Pompeii buried by the eruption of Mount Vesuvius in 79 C.E., charcoal from a campsite at Stonehenge, and corncobs from a cave in New Mexico. He also used radiocarbon dating to determine that the last North American ice age ended about ten thousand years ago, not twenty-five thousand years ago as had been believed.

Libby remained on the faculty at the University of Chicago until 1954, when President Dwight D. Eisenhower appointed him to the U.S. Atomic Energy Commission (AEC). Libby had previously served as a member of the Committee of Senior Reviewers of the AEC from 1945 to 1952. Libby, the first chemist to serve on the AEC, headed Eisenhower's international "Atoms for Peace" program, which supplied equipment and information on the peaceful uses of atomic energy and radioactive materials to schools, hospitals, and research institutions around the world. Libby also studied the effects of radioactive fallout. He served on the AEC until 1959, when he became professor of chemistry at the University of California, Los Angeles (UCLA). He was appointed director of the Institute of Geophysics and Planetary Physics at UCLA in 1962, a position he held until his death. While serving on the AEC, Libby held a position as a research associate of the Carnegie Institution's Geophysical Laboratory in Washington, D.C., so that he could continue his scientific research.

During the Cold War, Libby opposed efforts to ban testing of nuclear weapons. He proposed that every home should have a fallout shelter in case of nuclear war. In a widely publicized event, Libby built his own fallout shelter in his home. From 1959 to 1961, he served as consultant to the Office of Civil and Defense Mobilization. In 1961, he wrote a twenty-seven-page pamphlet published by the Associated Press titled "You Can Survive an Atomic Attack."

Libby divorced his wife in 1966 and married Leona Woods Marshall. He continued to explore applications of radioactive decay to geological problems. In 1977, he developed a method to monitor the emission of radon gas from earthquake-prone areas, detecting the alpha particle emitted when radon decays by using sensitive film. He suggested that an increase in radon emission might signal an upcoming earthquake. Libby died of a lung illness on September 8, 1980, in Los Angeles.

IMPACT

In 1960, Libby was awarded the Nobel Prize in Chemistry for his development of carbon-14 dating. Introducing Libby for the award, Professor Arne Westgren said that Libby had "succeeded in developing a method that is indispensable for research work in many fields and in many institutes throughout the world. Archaeologists, geologists, geophysicists, and other scientists are greatly indebted to you for the valuable support you have given them in their work."

Although archaeologists and geologists had other methods to determine the ages of certain types of samples, the carbon-14 method quickly proved more rapid and more accurate. Thus, Libby's radiocarbon dating method quickly attracted attention from the scientific community, and more than one hundred carbon-14 analysis laboratories were established around the world.

Archaeologists were able to establish time lines for human development and settlement that preceded the written record. Egyptologists, for example, employed Libby's technique to create a chronology of Egyptian rulers dating back to about 5000 B.C.E. The charcoal from campfires in Iraq was dated, showing that people lived in Iraq twenty-five thousand years ago. "Ötzi the Iceman," a frozen body found in the mountains of northern Italy in 1991, was also dated using Libby's technique. Samples of the iceman's bones, boot, leather, and hair show that he lived about fifty-five hundred years ago.

The most famous object dated using the radiocarbon technique is the Shroud of Turin—believed by some to be the burial cloth of Jesus Christ. Records of the shroud date back to the mid-fourteenth century. The presence of pollen spores from Israel on the cloth suggested that it might be a genuine relic. However, in the 1980's, small samples of the cloth were dated independently by three laboratories in Tucson, Oxford, and Zurich. Their results showed the cloth was made around 1300 C.E. and could not be a burial shroud from the time of Jesus Christ.

Monitoring the radiocarbon age of the water in a well system can aid in determining if overuse is depleting a region's water supply before the problem becomes so severe that there is a shortage. Oceanographers employ the carbon-14 method to date recent sea sediments. Carbon-14 dating has made accurate determinations of the rate of turnover of the deep water of the Earth's oceans. These results play an important role in studying one of the central problems of physical oceanography: determining how water circulates in the oceans.

—*George J. Flynn*

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See also: Hans Geiger; Ernest Orlando Lawrence.

CARL VON LINDE

German engineer

Linde was a key developer of modern refrigeration technology and of a technique for the liquefaction of large quantities of air to extract pure liquid oxygen and nitrogen.

Born: June 11, 1842; Berndorf, Bavaria (now in Germany)
Died: November 16, 1934; Munich, Germany
Also known as: Carl Paul Gottfried von Linde (full name)
Primary fields: Chemistry; mechanical engineering
Primary invention: Ammonia-compressor refrigerator

EARLY LIFE

Carl von Linde (kahrl von lihnd) was born June 11, 1842, in Berndorf, Bavaria. His father was a Lutheran minister. Linde first became interested in engineering when he attended high school in the town of Kempten. The father of one of his friends was the director of the local cotton-spinning mill, and Linde became a frequent visitor, fascinated by the mill's complex machinery. These experiences fueled his desire to pursue an education in the field. He received his father's permission to study mechanical engineering at the Federal Polytechnic in Zurich, Switzerland. Although he never officially graduated, he did receive letters of recommendation from some of the Federal Polytechnic's well-known professors.

Linde began his professional career in mechanical engineering at the workshop of the Kottern cotton-spinning mill near Kempten, and in 1865 he became an engineer in the drawing office of the Borsig company in Berlin. In 1866, he accepted the position of head of the technical office of a new Munich locomotive manufacturing factory, Krauss and Company. He married Helene Grimm on September 17 of that same year. The couple would eventually have six children: Maria, Franziska, Friedrich, Anna, Richard, Elisabeth. Linde had developed many research interests in addition to his business interests, and he entered the teaching profession as a result. In 1868, he received an associate professorship at the Polytechnic in Munich. By 1872, he had achieved the rank of full professor of mechanical engineering.

LIFE'S WORK

The first phase of Linde's teaching career would last from 1868 to 1879. After he became a full professor, the Bavarian government funded a machine laboratory at the Polytechnic for Linde and his students, the first such laboratory to be established in Germany. It was here that he began conducting his research experiments on heat theory and refrigeration. An 1871 Linde essay on improved refrigeration techniques had sparked interest in his work among breweries in Germany and other parts of Europe. Refrigeration machines would allow for year-round rather than seasonal brewing. Breweries' requests for his refrigeration machines spurred his research into ways to further improve them. By 1874, Linde had developed a methyl-ether refrigerator, and by 1876 he had developed an ammonia-compressor refrigerator. His refrigerators relied on a mechanical system of cooling gas. His model greatly improved on earlier models because of its reliability, efficiency, practicality, and portability. He also engineered and built ice factories that utilized his refrigeration techniques. He would distribute cooling throughout the factories through a method of circulating cold saltwater brine in a pipe cooling system mounted on the ceilings.

In 1877, the German Imperial Patent Office awarded Linde a patent for his ammonia-compressor refrigerator and he decided to go into business to market his invention. The following year, he surrendered his professorship and established Linde's Eismaschinen AG (Society for Linde's Ice Machines), later known as Linde AG, headquartered in Wiesbaden. His company became an international success, selling its product to breweries, slaughterhouses, and cold-storage companies. Linde was actively involved in various technical associations while also running his company. In 1894, after receiving a request to develop a new cooling method from the Guinness brewery in Dublin, Ireland, Linde decided to withdraw from his active role in managing his company to once again focus on research.

Linde's new research conducted during the 1890's would lead to his next major discovery, a process for liquefying air (and later other gases) by cooling it in stages that came to be known as the Linde technique. By 1894-1895, Linde was able to liquefy air by compressing a small quantity in a machine, and then allowing it to expand rapidly, which cooled the air. The already-cooled air would then be used to cool additional air that would enter the machine. Additional repetition of the process would eventually result in liquefaction. The method was based on the Joule-Thompson effect pioneered by James Prescott Joule and William Thomson (Lord Kelvin) and

THE AMMONIA-COMPRESSOR REFRIGERATION MACHINE

Carl von Linde's early research career sprang from his desire to improve the refrigeration technology of his day. He set out to build upon the earlier work of scientists such as Dr. William Cullen, Dr. John Gorrie, and Michael Faraday. He developed his first refrigeration machine in 1874 at his newly built machine laboratory at the Munich Polytechnic, utilizing the principle of cooling gas, a compressor-based technology, and methyl ether as his refrigerant. Linde was not happy with the first machine, however, because its mercury seal did not work properly and methyl ether leaked from the compressor. He then built a second machine, with the help of his student assistant Friedrich Schipper. The new machine featured a new compressor design with a more effective seal and used ammonia as a refrigerant. Ammonia proved to be more efficient, and the second machine had the added benefits of being half the cost and weight of his first machine. Linde received a Bavarian patent for his new ammonia-compressor refrigeration machine in 1876 and a German Reichspatent in 1877. A third design featured gas pumps and a horizontal rather than vertical structure.

Linde not only conducted groundbreaking research into the basic laws of physics but also proved to be an astute businessman who knew how to get his invention onto the commercial market. He pioneered both the technology behind the machine and the engineering of the machine itself in addition to forming his own company to market the machines. Linde's company served as a model for science-based industry and grew to become a worldwide corporation, which is still in existence under the name Linde AG. Linde's work on his refrigerator also spurred his later pioneering work in air liquefaction, when the Guinness brewery of Dublin, Ireland, asked him to develop a new cooling technique in the 1890's. The result would be the Linde technique for liquefying air.

Modern refrigerators use a similar process of evaporation utilized by Linde's ammonia-compressor refrigeration machine, using a substance known as a refrigerant to displace heat from the inside to the outside. Standard parts include the compressor, which compresses the refrigerant, raising the pressure and temperature inside the refrigerator; the heat-exchanging pipes located outside the refrigerator, which dissipate the heat inside the refrigerator; and the liquid refrigerant. The refrigerant cools down, condenses, and absorbs the heat to cool the refrigerator, becoming warmer and expanding before continuously repeating the cycle. Early refrigerators used a gas flame to heat the ether or ammonia, while more current models use a safer electric heating unit. Ammonia is not in common use today because of the discovery of less toxic refrigerants. Refrigerators became mass-produced in the 1940's and are now present in most households.

the countercurrent technique. Linde also returned to academia during this period, first as an honorary professor, and later, in 1900, as a full professor without teaching duties.

By 1902, Linde had utilized his method to separate pure liquid oxygen and nitrogen from liquefied air. In 1903, he received patents in the United States for the Linde oxygen process and the machine used in producing the liquid oxygen. Linde achieved worldwide recognition for his work. His honors included three honorary doctorates, the Bavarian Crown Achievement Medal, and his elevation to personal nobility status. During this period, Linde did not completely abandon his outside and business interests. The Linde company continued to flourish, also launching a number of subsidiaries around the world. Linde personally served on the supervisory boards of some of his company's subsidiaries as well as the boards of outside companies, including the locomotive manufacturer Knauss and Company, where he had once worked.

He was also one of the founders of both the Bavarian Boiler Review Association, where he served as chairman for a time, and the Munich Thermal Testing Station. He examined Bavarian patent applications and served on a Berlin commission that reformed German patent law. He was appointed to the board of trustees of the German Physical-Technical Institute in 1895. He was appointed to the Bavarian Academy of Science in 1896 and was appointed Bavarian district chairman of the Association of German Engineers (VDI) in 1892 and its president in 1904. In 1898, he joined the Göttingen Association for Applied Physics and Mathematics, a forerunner of the Kaiser Wilhelm and Max Planck societies. In 1903, he cofounded the Deutsches Museum in Munich, serving on its board for many years. Linde also found time to write a memoir entitled *Aus meinem Leben und von meiner Arbeit* (1916; from my life and about my work). Carl von Linde died on November 16, 1934, in Munich at the age of ninety-two.

IMPACT

The Linde technique for the liquefaction of air made possible for the first time the timely and cost-effective production of commercial quantities of liquid air. His process for separating oxygen from the liquid air through the apparatus he invented made oxygen a common commodity in both the medical and industrial worlds. Uses for his liquid air products include the oxyacetylene torch, which revolutionized metal cutting and welding, rocket fuel, and the manufacture of steel. Variations of his methods have remained in use long after his passing, as other scientists have utilized them to liquefy gases such as hydrogen. His work also proved to be an important basis for research in the area of low-temperature, high-vacuum physics.

His process of liquefying gases in large quantities also allowed the development of modern refrigeration technology, of which his refrigeration machines were a pioneering example. Although Linde was not the first scientist to use condensed ammonia in a refrigeration machine, he developed the first practical and portable refrigeration systems. Modern refrigeration has vastly improved the ability to produce, store, and handle food safely because of its inhibition of the growth of dangerous bacteria, mold, and yeast that can sicken consumers. Linde AG grew into an international company that has worked in a variety of areas, including the manufacture of refrigeration and air-conditioning systems, the production of rare gases, and the construction of industrial plants of various types. Carl von Linde's lasting impact was his ability to follow an invention from the idea, to the design, to the production and marketing of that design.

—*Marcella Bush Trevino*

FURTHER READING

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Dienel, Hans-Liudger. *Linde: History of a Technology Corporation*. New York: Palgrave Macmillan, 2004. Provides an in-depth exploration into the business aspect of Linde's career through a history of the Linde Group and its role as a global technology company in the areas of engineering, materials handling, and refrigeration.

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See also: Rudolf Diesel; Frederick McKinley Jones; Lord Kelvin; Roy J. Plunkett.

EDWIN ALBERT LINK

American underwater archaeologist and aviator

Link invented the flight simulator—a training device that allows pilots to develop the skill of flying using flight instruments while they remained on the ground—as well as several devices for undersea exploration.

Born: July 26, 1904; Huntington, Indiana
Died: September 7, 1981; Binghamton, New York
Also known as: Edwin Albert Link, Jr. (full name)
Primary fields: Aeronautics and aerospace technology; naval engineering
Primary inventions: Link Trainer (flight simulator); submersible decompression chamber

EARLY LIFE

Edwin Albert Link, Jr., was born on July 26, 1904, in Huntington, Indiana. He was the youngest son of Katherine (Martin) and Edwin A. Link, Sr. His father worked at the Schaff Brothers Piano Company in Chicago, Illinois. In 1910, the family moved to Binghamton, New York, when the senior Edwin bought the Binghamton Automatic Music Corporation, which he renamed the Link Piano and Organ Company. The company manufactured player pianos, nickelodeons, and theater organs.

At an early age, Link showed great mechanical ability, but he was not interested in academic subjects. His parents separated in 1918, and Link moved frequently, attending the Rockford Training High School in Illinois, Los Angeles Polytechnic High School, Bellefonte Academy in Pennsylvania, and the Lindsley Institute in West Virginia.

News accounts of aircraft fighting in World War I stimulated Link's interest in aviation. He took his first flight in 1920. Link returned to Binghamton in 1922, attending Binghamton Central High School while working at his father's piano company. He learned about mechanical devices and the principles of compressed air, and he quickly developed the skill to repair and rebuild organs. Link kept his creative mind busy, thinking about devices he might build to accomplish specific tasks. In 1924, he filed his first patent application, for a device that removed lint from player piano rolls.

Link's interest in flying continued, but he could not take lessons very often because of the cost of the plane rental. Frequently, he could only afford to taxi a friend's plane along the airport runway, learning how to move his hands and feet on the aircraft controls, without actually flying. Link flew whenever he could afford lessons. He made his first solo flight in 1926.

LIFE'S WORK

In 1928, Link convinced his mother to help him buy a small Cessna airplane. By that time, he had received his pilot's license and wanted to pursue a career in aviation. He worked on a device designed to make flight training less expensive and safer. He built the prototype of his flight simulator, the Link Trainer, in the basement of the organ factory using parts from an organ. After a year and a half, he succeeded in getting his simulator to mimic the response to control movements that he experienced in his own airplane. He filed a patent application for the Link Trainer in March, 1930, and established the Link Aeronautical Corporation in Binghamton to build and sell his aviation trainer.

Much to Link's surprise, his trainer was a success with amusement park operators, who used it as a coin-operated ride, but aroused little interest at flight-training schools. Link established the Link Flying School in 1930. Using the Link Trainer as the major training device, he guaranteed each student could learn to fly for only $85. However, the Depression made flying too expensive for most people, so Link worked at airports, managing the operations, refueling airplanes, and piloting. Link designed an illuminated sign, which he suspended below his airplane, selling advertising to local shop owners. His "electric sky sign" was only visible at night, and night flying requires more extensive use of the aircraft instruments. He quickly realized that the Link Trainer, equipped with more advanced instruments, could provide night and bad-weather flight training.

In 1931, Link married Marion Clayton, a reporter for a Binghamton newspaper. She took over managing

THE LINK TRAINER

The first flight simulator was designed and built by Edwin Albert Link in 1929 to allow pilots to practice flight maneuvers while they were on the ground. Link used the knowledge of mechanical devices and the operation of bellows, knowledge gained while working in his father's organ company, to construct a mechanical device that responded to control movements in the same way that an airplane responded, simulating the motions experienced during airplane flight. The Link Trainer had two basic components, the training compartment and the instructor's station.

The training compartment, which looked like a large toy airplane, was built from parts available in the organ factory. It was simply a wooden box shaped like the cockpit of an airplane and attached to short wooden wings. The box sat on a universal joint, a device that allows the cockpit to tilt in any direction, mounted on a turntable. The cockpit contained a pilot's seat, a set of aircraft controls, and flight instruments. The motion of the cockpit was driven by several bellows, which were controlled by valves that regulated their pressure in response to the movement of the control wheel or stick and the rudder pedals. This combination allowed the cockpit to move around any of the three axes. The cockpit pitched up and down and rolled side to side as it simulated the movement of an actual airplane in response to the flight controls.

The instructor sat at a table outside the cockpit. He had a display that repeated the flight instruments in the cockpit, a large map, and a marker, called a "crab," that moved across the map tracking the course of the simulated flight. The pilot and instructor talked to each other using headphones and microphones to simulate radio communications.

The student had to rely on the readings on the instruments to fly the simulator through a series of maneuvers directed by the instructor, who followed the progress on the map. Advanced versions of the Link Trainer included simulation of the effects of air passing over the controls, making them more difficult to move as the speed increased, and a generator that simulated turbulence.

Link's businesses. They had two sons—William, born in 1938, and Edwin Clayton, born in 1941.

In the mid-1930's, aviation began to grow. The U.S. Army Air Corps took over transporting airmail for the post office in February, 1934, but within six weeks twelve pilots were killed. Many of them were inexperienced at flying in bad weather, so the Army Air Corps ordered six instrument trainers from Link's company. Japan bought ten Link Trainers, and orders from several European nations followed quickly. An improved instrument flying trainer was introduced in 1936.

In 1937, the company set up a production facility in Canada because a British contract required that the Link Trainers be manufactured in the British Commonwealth. Link's company expanded to other forms of aviation training. In 1939, with a contract from the British military, the company developed the Celestial Navigation Trainer, used to train aircraft navigators. In December, 1941, when the United States entered World War II, there was an immediate effort to produce military aircraft and to train pilots. Link's company, now called Link Aviation Devices, Inc., expanded rapidly.

The end of World War II resulted in cuts to the military budget and cancellation of orders for flight trainers. Link had anticipated this problem and established a marine division of his company that built boats and canoes for the newly emerging recreation market. In the early 1950's, the expansion of commercial airline activity around the world created a new demand for flight trainers, and the outbreak of the Korean War increased the military demand, so Link's company prospered.

Link sold his company to General Precision Equipment Corporation in 1954 and retired to pursue sailing and underwater exploration, particularly underwater archaeology. Documents showed that wrecks from the "Spanish treasure fleet," ships that carried gold, silver, and gems collected by the Spanish armies from the Americas, were undiscovered along the Florida Keys and eastern coast. Finding the wrecks and recovering their treasure posed new engineering challenges.

Link bought a shrimp trawler in May, 1952, and converted it into an expedition ship, which he named the *Sea Diver*. Link began organizing expeditions to find the treasures, ultimately developing systematic search and archaeological exploration procedures and inventing complex machinery to assist the divers. Link designed the *Reef Diver*, a shallow draft search boat; an airlift, a device that carefully moved sand away from the wrecks; and a magnetometer that was towed behind a boat to search for metal on the ocean floor.

Link and his wife spent the summer of 1955 searching for the wreck of the *Santa María*—the ship Christopher Columbus lost on his voyage to the Americas—off the coast of Haiti. They found an anchor that dated from the correct era but could not determine whether it came from the *Santa María*. They found no sign of the ship itself. Later that summer, the couple visited the Bahamas, trying to trace the route Columbus sailed to the New World. Using translations from Columbus's journal and his own on-scene exploration, Link suspected that Columbus landed first on the Caicos Islands, then the Bahamas, and eventually Cuba. He described his idea in "A New Theory on Columbus's Voyage Through the Bahamas," which was published in 1958 by the Smithsonian Institution.

Link ended his retirement in 1957, assuming the presidency of General Precision Equipment Corporation, a position he held for two years. During that period, he developed the submersible decompression chamber, a combination diving bell and decompression chamber that allowed divers to work in deep water. With Link's device, the air pressure and gases could be controlled to prevent nitrogen narcosis, an illness caused by the absorption of too much nitrogen in the body. He also had a new ship built—the *Sea Diver II*, designed and equipped for archaeological research.

Link headed a group of civilian specialists assisting the U.S. Navy in the search for the nuclear submarine *Thresher*, which sank in April, 1963. In 1965, he designed a submersible exploration vehicle with a special compartment, based on his submersible decompression chamber, for divers. The *Sea Diver*, launched in January, 1966, and later renamed *Deep Diver*, allowed researchers to view marine life in its natural environment at depths up to 1,250 feet. His later design, the *Johnson-Sea-Link*, weighed eighteen thousand pounds and could operate to a depth of 3,000 feet, letting divers out down to 1,500 feet.

Link's son Clayton and another diver, Albert Stover, died during a routine dive when the *Johnson-Sea-Link* became tangled in the wreckage of a destroyer sunk off the Florida coast. This personal tragedy resulted in Link's effort to develop the Cabled Observation and Rescue Device (CORD). Link died on September 7, 1981. A few days before he passed away, the city of Binghamton renamed its airport Edwin A. Link Field.

IMPACT

During his career, Link patented more than two dozen inventions, mostly for flight training or deep-sea exploration. The Link Trainer decreased the cost and increased the safety of pilot training. By 1940, Link Trainers had been sold to more than thirty-five countries. During World War II, Link Trainers became standard training equipment at all pilot-training facilities in the United States. More than ten thousand trainers were delivered, and more than 500,000 military pilots were trained in them.

When Link's interest turned to undersea exploration, his inventions had a similar impact. Link's submersible decompression chamber became a major part of his Man-in-Sea project, funded by the National Geographic Society, to permit divers to work for sustained periods at ocean depths up to one thousand feet. This joint effort with the French undersea pioneer Jacques Cousteau used Link's submersible decompression chamber as the transport to and from an underwater home designed by Cousteau. Link's submersible decompression chamber and later his submersible exploration vehicle allowed the divers to adapt to the pressure during the descent and to begin decompression as soon as they returned to the vehicle, saving valuable time for undersea activities.

—*George J. Flynn*

Further Reading

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See also: George Cayley; Jacques Cousteau; Jay Wright Forrester; Charles E. Taylor; Wilbur and Orville Wright.

HANS LIPPERSHEY

Dutch spectacle maker

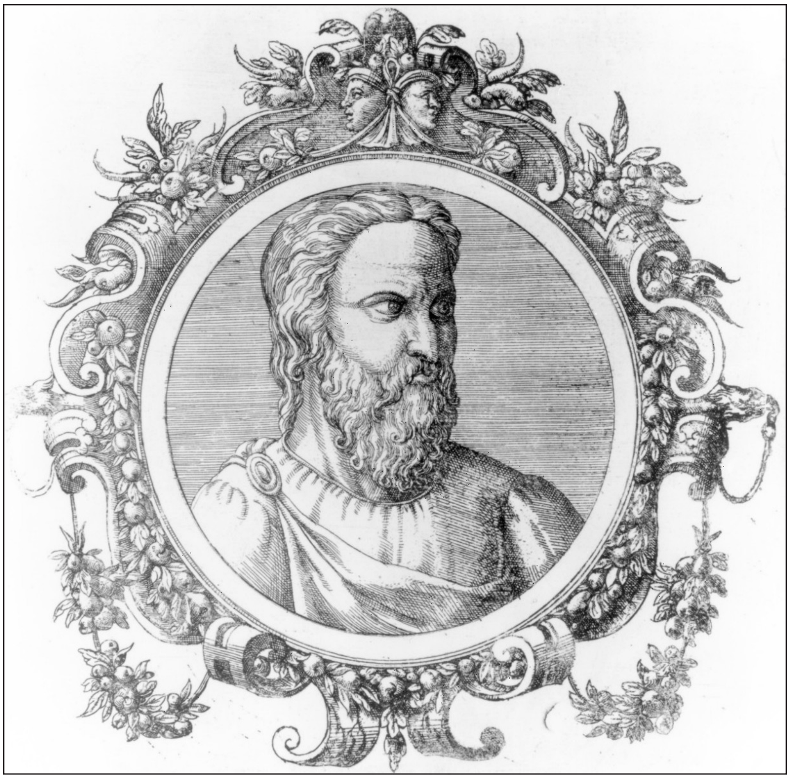
Lippershey was the first person with good documentary evidence for his discovery of what later came to be called the refracting telescope. He made several monocular and binocular telescopes for the Dutch government and military.

Born: c. 1570; Wesel, Westphalia (now in Germany)
Died: September, 1619; Middelburg, Zeeland, United Provinces (now in the Netherlands)
Also known as: Hans *or* Jan Lippersheim
Primary fields: Military technology and weaponry; optics
Primary invention: Refracting telescope

Early Life

Hans Lippershey (hahnz LIHP-pur-shay) was born in Wesel, a small town in present-day western Germany, only sixteen miles south of the border of the United Provinces (now in the Netherlands). Uncertainty exists about the date of his birth, though most sources give 1570 as the year. He probably received little formal schooling, since the astronomer Christiaan Huygens later described him as an "illiterate mechanick." Religious conflict between Roman Catholics and Protestants may have played a role in the family's move to Zeeland in the southwestern United Provinces, since many Protestants fled across the border after the Spanish forces took Antwerp in 1585. The Lippersheys settled in Middelburg, the capital of Zeeland, which had become a flourishing city as a result of the many Protestant artisans who founded businesses there. Italians introduced new glassmaking techniques to Zeeland in the 1590's, and the making of spectacles became a profitable trade.

It is likely that the adolescent Hans was apprenticed to a master lens maker for the usual period of seven years. In later documents, he is described as "pious and God-fearing," and this religiosity and his accomplishments



Hans Lippershey. (Library of Congress)

as a lens maker indicate that he must have been a dutiful apprentice. If he followed the traditional course of the apprenticeship system, he must have become a journeyman and saved enough money to go into business in Middelburg as a maker of spectacles. He felt secure enough financially to marry in 1594. Middelburg proved to be an excellent location for Lippershey's business. The city had the only glass factory in Zeeland, and high-quality Venetian glass often was shipped there. Because of his skills as an artisan and because of his commercial good sense, his business prospered, and he became a Dutch citizen in 1602.

LIFE'S WORK

As a master lens maker and spectacles maker, Lippershey was able to take on apprentices and hire journeymen, both of whom aided in the expansion of his business. He might have remained an instance of those artisans who performed valuable services in their communities but who did nothing that would be noted by historians. However, historians have credited him with the discovery of the telescope, and this has raised many questions: Was he the first? Did he do it alone or with others? Was his discovery accidental or planned? Because of the paucity of evidence, stories have gathered about this pivotal discovery. In one story, which has several variants, in 1608 two children were playing with glass lenses that had been shaped and polished for use in Lippershey's shop (some accounts state that they were his own children, others that it was a single apprentice, and still others that it was Lippershey alone). When one of the children (or an apprentice) held one lens close to an eye and the other at arm's length, and then looked through them, a distant church steeple appeared nearer and larger. The child or apprentice showed this phenomenon to Lippershey, either immediately or when he returned to his shop. After verifying this finding for himself, Lippershey quickly grasped its importance.

Having ascertained the best distance between the lenses for a focused image, he preserved this orientation in a metal or wooden tube, thus creating what would later be called a telescope. Lippershey named it a *kijker* (Dutch for "looker"), but other terms later proliferated, including "optic tube," "perspective glass," and "Dutch trunk." ("Telescope" was coined by the Greek scientist Giovanni Demisiani.) Varied accounts also exist about what lenses were actually in Lippershey's tube. Some interpreters state that both the ocular lens (near the eye) and the objective lens (near the object) were convex—that is, thicker in the middle than at the edges, in which case the image would be upside down. The more common interpretation is that the ocular lens was a short-focal-length concave lens and the objective was a long-focal-length convex lens, in which case the observed image would have been right side up. Whatever the details of his discovery and the design of his device, Lippershey, an astute businessman, recognized its potential military and commercial (though not astronomical) applications. Holland was at war, while it was also extending its trade throughout Europe and even to the Far East, so generals and captains would certainly find Lippershey's "looker" advantageous in their endeavors.

The first clear documentary evidence for the invention of a telescope was a letter, dated September 25, 1608, in which Zeeland's Committee of Councilors, in writing to their delegation at the states-general in The Hague, stated that this letter's "bearer" (Lippershey) claimed to have invented a device by which things at a distance appear as if they were nearby. A week later, Lippershey applied for a thirty-year patent or a pension for his invention. He demonstrated his device to Prince Maurice of Nassau, the stadtholder of the states-general and the commander in chief of the Dutch armed forces. Within a short time, other claimants appeared, stating that they had already invented this device or made superior models. Although Dutch officials wanted to keep this invention secret, and enjoined Lippershey to do so while he worked on a binocular version of his device, knowledge of his discovery spread rapidly, not only through the Low Countries but also to France, Germany, and Italy.

The states-general formed a committee to study Lippershey's (and others') claims, and Lippershey was requested to construct binocular versions of his device, for which he was paid three hundred guilders on October 4, with a stipulation of further payment of six hundred guilders when he completed his task. On December 11, Lippershey delivered the first of his binocular telescopes, with lenses made of rock crystal instead of glass. Committee members inspected and tested the device and found it satisfactory. Four days later, Lippershey received a payment of three hundred guilders, with the promise of another three-hundred-guilder installment when he produced two other binocular telescopes. To his disappointment, he also learned that his patent had been denied because others had shown that they had knowledge of the invention. Nevertheless, he completed his task, received his final payment, and returned to Middelburg.

In the years following his discovery, Lippershey experimented with improved lenses, the spacing of the lenses within the tube, and tube lengths. He was able to interest the Dutch army and navy in these instruments because they allowed enemy combatants to be seen before the enemy was able to see the Dutch forces. Lippershey lived for more than a decade after his discovery of the telescope, and he must have received information on its diffusion throughout

WHO DISCOVERED THE TELESCOPE?

The idea of the telescope long antedates its realization. Archeologists have found lenses from 2,000 B.C.E., and ancient Greeks and Romans knew of the magnifying power of certain lenses—though for near, not distant, objects. Spectacles were a medieval invention, and in the thirteenth century Roger Bacon, an English Franciscan friar, wrote extensively on the optical properties of lenses and mirrors, and he may have combined lenses to enlarge distant objects. During the sixteenth century, the number of persons who may have developed telescopic devices increased. For example, Thomas Digges claimed that his father had used "angled glasses" to see far-off things. In his writings on optics, the English mathematician William Bourne reported how certain ground lenses gave distant objects the appearance of a "marvellous bigness." In a work published in 1589, the Italian philosopher Giambattista della Porta wrote that a combination of convex and concave lenses would permit the observer to see distant objects larger than they would otherwise appear. However, scholars have pointed out that none of these early claims resulted in concrete instruments that were tested and then influenced the course of developments.

Because of this lack of instruments or unambiguous documentary evidence, most scholars assign the telescope's origin to Hans Lippershey in 1608, since he actually made telescopes, and documents exist to support his claims. However, counterclaims appeared soon after Lippershey's application for a patent. For example, an instrument maker from Alkmaar, Jacob Adriaanzoon, more commonly known as Jacob (or James) Metius, petitioned the states-general for a patent, but he was never able to produce his device. Zacharias Janssen, who lived in Lippershey's city of Middelburg, was later brought into the controversy over the telescope's origin by his son and daughter. After Janssen's death, his son claimed that Janssen had invented the telescope, but estimates of the father's birth date make the son's claim unlikely. In fact, the daughter believed that her father had invented the telescope in 1611, years after Lippershey's documented invention. Galileo is also sometimes stated to be the inventor of the telescope, but he always denied this appellation, reserving that honor for Lippershey.

Because it is relatively easy to combine lenses into a telescope, people before Lippershey may well have used two lenses to magnify distant objects, but since documentation does not exist to verify this, these claims have been largely dismissed. The certitude that does exist over Newton's invention of the reflecting telescope will never exist for Lippershey's invention of the refracting telescope, but Lippershey's is the telescope that historical evidence shows was the start of this instrument's evolution, and so scholars continue to trace its origin to Lippershey.

Europe. Since he was illiterate, he could not have read Galileo's *Sidereus nuncius* (starry messenger) when it was published in 1610, but he may have heard from others about Galileo's wonderful astronomical discoveries, when the Italian astronomer turned his telescope to the heavens. After February 13, 1609, when documentary evidence states that Lippershey fulfilled his agreement on binocular telescopes, nothing certain is known about his life, until the notice of his burial in Middelburg on September 29, 1619.

IMPACT

Although no instrument has had a greater influence on astronomy than the telescope, Lippershey thought that his invention would be important for armies and navies, and, indeed, military personnel did use telescopes for the surveillance of enemy forces. However, most historians of science date the start of modern astronomy to 1609, when Galileo used his telescope, based on Lippershey's conception, to resolve the Milky Way into its thousands of stars, to observe the craters and mountains on the Moon, and to discover four satellites of Jupiter (now called Galilean moons). He later discovered telescopically that Venus, like the Moon, passes through phases and that the Sun has black spots on its surface. In his book on these discoveries, *Sidereus nuncius*, Galileo mentioned that he learned of Lippershey's invention through correspondence with a French scientist.

Lippershey's invention of the refracting telescope was important during the early history of astronomy, but this telescope's unfortunate tendency toward spherical and chromatic aberration meant that images were often fuzzy and distorted. Isaac Newton's invention of the reflecting telescope mitigated these problems, and during the eighteenth, nineteenth, and twentieth centuries reflecting telescopes were the prime conduit for astronomical observations and discoveries. For example, Edwin Hubble in the twentieth century was able to use the hundred-inch reflecting telescope on Mount Wilson in California to resolve galaxies into individual stars. The Hubble Space Telescope, named in his honor, has continued the long and fruitful history of the telescope by discovering distant galaxies and other wonders that bring us close to the origins of the universe. Earlier telescopes had mapped the crater on the Moon and discovered the asteroid that have been named in Lippershey's honor.

—*Robert J. Paradowski*

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See also: Roger Bacon; Galileo; Christiaan Huygens; Zacharias Janssen; Sir Isaac Newton; Bernhard Voldemar Schmidt.

Gabriel Lippmann

French physicist

Lippmann is best known for the innovation that won him the 1908 Nobel Prize in Physics: a revolutionary color-photography process based on the interference phenomenon. His other inventions include the capillary electrometer and the coelostat.

Born: August 16, 1845; Hollerich, Luxembourg
Died: July 13, 1921; At sea, en route to France from Canada
Also known as: Gabriel Jonas Lippmann (full name)
Primary fields: Astronomy; photography; physics
Primary invention: Color photography plate (Lippman plate)

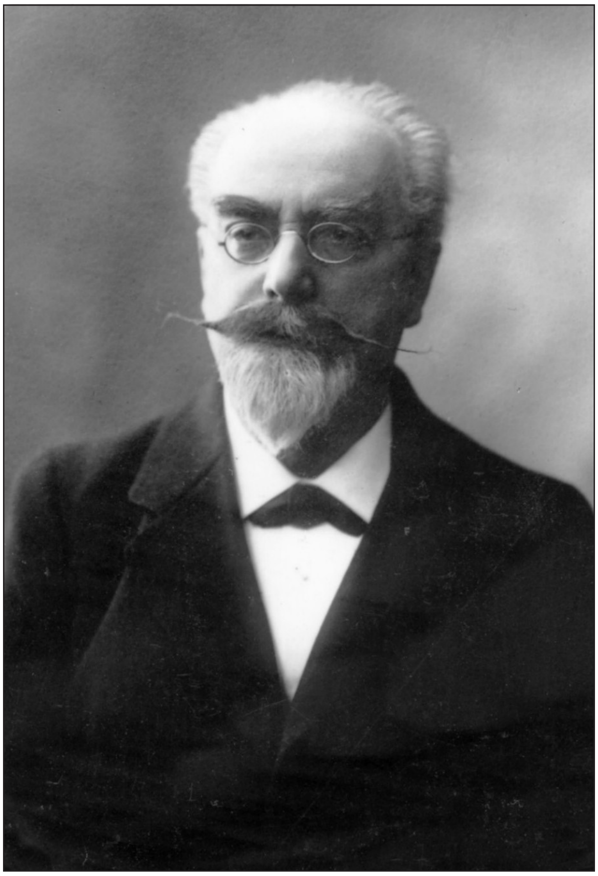
Early Life

Gabriel Jonas Lippmann (gah-bree-ehl joh-nahs lihp-mahn) was born in 1845 in Hollerich, Luxembourg, to French parents. His mother was from Alsace, and his father, who ran a tannery and glove factory, hailed from Lorraine. When Lippmann was a small boy, his parents moved the family to France and settled in Paris. He received his early education at home from his mother. In 1858, the thirteen-year-old Lippmann began studies at the Lycée Napoléon. He continued his studies at the École Normale, which he entered a decade later. While highly intelligent, Lippmann did not excel at school, as he focused only on the subjects that piqued his interest. When he took the government qualifying examination to become a teacher, he failed it.

While at the École Normale, he summarized articles originally written in German for the French chemistry and physics publication *Annales de Chimie et de Physique*. His translation work kept him abreast of the latest experimental work in electricity. Because of his linguistic skill and scientific knowledge, the French government appointed him to travel to Germany in 1873 as part of a mission to study methods of teaching science. In Heidelberg, Lippmann worked in the laboratory of physicist Gustav Kirchhoff, who was known for his research into electrical circuits, spectroscopy, and black-body radiation. There, Lippmann also worked with physiologist Wilhelm Kühne, who introduced him to an experiment in which a drop of mercury coated with sulfuric acid contracted when it was touched with an iron wire and recovered its original shape when the wire was removed. In 1874, the University of Heidelberg awarded Lippmann a doctorate in philosophy. While in Germany, Lippmann did additional work with Hermann von Helmholtz, a physics professor conducting research in electromagnetism at the University of Berlin.

Life's Work

During his time abroad, Lippmann experimented with the mercury phenomenon Kühne had shown him. Lippman theorized that the observed behavior was the result of a connection between electric polarization and surface tension. From his research, he created a capillary electrometer. This exceptionally sensitive instrument, capable of detecting differences in electrical potential as small as one one-thousandth of a volt, measured potential using changes in the surface tension between mercury and dilute sulfuric acid within a small-diameter tube. In 1875, the Sorbonne in Paris awarded him a doctorate for his work. The following year, Lippmann pub-



Gabriel Lippmann. (©The Nobel Foundation)

COLOR PHOTOGRAPHY

Gabriel Lippmann based his color photography method on the phenomenon of interference. Interference colors are produced when light waves combine to intensify one another or cancel one another out. The colors seen in soap bubbles, peacock feathers, butterfly wings, mother-of-pearl, and oil slicks on wet roads are all produced by interference.

Lippmann's method involved coating a glass plate with a fine-grain, light-sensitive emulsion. The plate was placed emulsion side down in a holder that contained a layer of mercury, and the holder was introduced into a camera with the emulsion side facing away from the lens. The mercury that was in contact with the emulsion acted as a liquid mirror. Light waves that entered the camera through the lens were reflected back on themselves by this mirror. Interference between the oncoming and reflected light waves created standing waves in the emulsion, and the emulsion formed a recording of the standing wave pattern in thin layers of silver. After the plate was processed, it was viewed in white light. The layers of silver reflected the light, with every point on the plate selectively reflecting the color that was imprinted on it during exposure.

Lippmann's breakthrough, Nobel-winning process produced permanent, true-color images; there were no dyes or pigments to fade over time, and the color seen in the image was the actual spectral color of the subject photographed. However, while Lippmann photographs were beautiful and lasting, his method was too problematic for it to retain a foothold as a commercially viable process. Only a high-quality, very fine grain emulsion would work, but the fine grain meant long exposure times of several minutes, or even hours. The final image could not be copied, and it had to be viewed at the correct angle and under proper lighting conditions.

Nevertheless, the method intrigued other researchers in the field. Between 1891 and 1910, the Lumière brothers, Hans Lehmann, and others experimented with the process, making their own refinements. The Lumières cut exposure time down to a minute with their use of a very fine grain silver-halide gelatin emulsion; this became the standard emulsion for Lippmann photography. Later, Lehmann perfected an emulsion upon which the producers of commercial Lippmann plates based their formulas.

While Lippmann photography could not gain ascendancy as a commercial method, researchers and hobbyists continued to explore and refine it. To date, it remains the only method for correctly imaging spectra. The fact that Lippmann images cannot be reproduced may have security applications, and their long-term stability may make them useful for archiving purposes. The process has been of special interest to those working in holography, as both holograms and Lippmann photographs involve encoding an image using interference, recording the interference structure on a photographic plate, and reconstructing the image through the diffraction of light. High-resolution panchromatic recording materials commercially available for holography have been adopted for modern Lippmann photography.

Lippmann's color photographs are housed at the Musée de l'Elysée in Lausanne, France.

lished his findings that the phenomenon worked in reverse: Mechanically altering a drop of mercury coated in sulfuric acid affected the electrical charge between the two liquids.

In 1878, Lippmann joined the Faculté des Sciences, a laboratory in Paris. There, he became professor of mathematical physics in 1883. In 1886, the year he was admitted as a member of France's prestigious Académie des Sciences, he became professor of experimental physics at the Faculté. He was subsequently appointed director of the laboratory, a position he held for the rest of his life. As director, he oversaw the transfer of the Faculté des Sciences when it became incorporated into the Sorbonne.

In 1891, in a short communication to the Académie des Sciences, Lippmann presented his process for the photographic reproduction of color based on the phenomenon of interference. He had developed the theory of the process as early as 1886 but had struggled with successful execution for years. He was still working to resolve problems with the photographic film's variable sensitivity to different parts of the spectrum. In 1893, he was able to show the Académie photographs taken by Auguste and Louis Lumière that reproduced natural color using Lippmann's method. In 1894, he published his complete theory.

In 1895, Lippmann made a valuable contribution to astronomy with the invention of the coelostat, a device used in photographing stars. At the time, instruments called siderostats were commonly employed to keep the image of a single star stationary despite the movement of the star itself; however, images of surrounding stars would rotate around a single point. Lippmann's coelostat, which involved the use of a mirror and a machine that reproduced the Earth's rotation, held the image of an entire area of sky immobile long enough for photographic exposure. Lippmann also invented a related device, the uranograph, which produced a photographic sky map with longitudes automatically printed on it.

Also in 1895, Lippmann proposed a method to eliminate the personal equation (an individual's observational bias) in measuring time through photographic registration (the creation of visual records on rotating rolls of photographic paper). Two years later, he published on the use of the stroboscopic method to compare the oscillations of two pendulums. In 1901, he wrote of a new form of galvanometer (an instrument for measuring the intensity of an electric current). Lippmann would later write on another field, seismology. He proposed the use of telegraphy to detect and measure earthquakes, and he devised a new form of seismograph that would measure acceleration.

In 1908, Lippmann was elected as a Foreign Member of the Royal Society of London. That same year, he was awarded the Nobel Prize in Physics for his method of reproducing colors in photography based on the interference phenomenon. In 1912, he was elected president of the Académie des Sciences. Other organizations with which he was associated during his career include France's Institut d'Optique Théorique et Appliquée, of which he was a founding member, the Bureau des Longitudes, and the Grand Ducal Institute.

In the summer of 1921, Lippmann and his wife (novelist Victor Cherbuliez's daughter, whom he married in 1888) visited North America. Lippmann made the trip as a member of an official commission traveling to Canada to express France's gratitude for aid during World War I. On the return trip to Europe aboard the steamer *France*, Lippmann died at sea. He was seventy-five.

IMPACT

Lippmann is most often remembered as the Nobel Prize winner who invented interference color photography. Yet his accomplishments extended far beyond a single discipline or intellectual pursuit. During his career of almost half a century, the physicist made significant contributions to nineteenth century studies of electricity, thermodynamics, optics, astronomy, seismology, photochemistry, and more—as a theoretician, an academician, and an inventor.

One of Lippmann's earliest inventions played a vital part in the first recordings of the electrical activity of the heart. In 1876, French researcher E. J. Marey employed the Lippmann capillary electrometer in measuring electrical variations in the exposed muscles and heart of a frog. British physiologist Augustus Desiré Waller used the instrument in 1887 to record the first human electrocardiogram. An 1889 demonstration that Waller conducted influenced Dutch physiologist Willem Einthoven, who went on to conduct groundbreaking electrocardiogram research of his own. These early experiments, made possible by Lippmann's invention, are the forerunners of modern electrocardiography.

Lippmann influenced the scientific world not only through his own work but also through that of the students whom he taught and mentored. Notable among these are Pierre Curie, whose doctoral thesis Lippmann approved, and Marie Sklodowska, who did her thesis work in Lippmann's laboratory and reported to him as an advisee. In 1898, after she had become Marie Curie, her first paper before the Académie des Sciences was delivered on her behalf by Lippmann.

—*Karen N. Kähler*

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See also: Willem Einthoven; Dennis Gabor; Leopold Godowsky, Jr.; Hermann von Helmholtz; Auguste and Louis Lumière.

M. STANLEY LIVINGSTON

American nuclear physicist

Livingston, working with Ernest Orlando Lawrence, built the world's first cyclotron for the study of the atomic nucleus. Later, he designed and built many other particle accelerators that made possible the modern very high-energy accelerators used in nuclear research.

Born: May 25, 1905; Broadhead, Wisconsin
Died: August 25, 1986; Santa Fe, New Mexico
Also known as: Milton Stanley Livingston (full name)
Primary field: Physics
Primary invention: Cyclotron

EARLY LIFE

Milton Stanley Livingston was born in Broadhead, Wisconsin, on May 25, 1905, to Milton McWhorter Livingston and his wife, Sarah Jane. His father was a divinity student who later became pastor of the local church. The church paid so little that Livingston's father decided to take a job as a schoolteacher in Southern California, where the family bought a ten-acre orange grove and ranch. As the only son, Stanley Livingston did most of the ranch chores. Through his work with the farm machinery and automobile engines, he became very interested in machines and technology and became expert in their uses and operations.

After graduating from high school, Livingston entered Pomona College in Claremont, California, to study chemistry, but later he switched to physics. He graduated from Pomona in 1926 and then went on to Dartmouth College, where he obtained his master's degree. After a further year at Dartmouth as an instructor, he moved to the University of California at Berkeley to study for a Ph.D.

At Berkeley, Livingston became interested in nuclear physics and asked a young physics professor, Ernest Orlando Lawrence, for a thesis project. Lawrence suggested that Livingston build a new type of cyclical charged particle accelerator for nuclear research. Livingston built the hardware for this new machine, now called a cyclotron, and showed that it could accelerate hydrogen ions. He obtained his Ph.D. in 1931 after producing a thesis titled "Acceleration of Particles to High Energies Without the Use of High Voltage."

LIFE'S WORK

The first proton accelerator for nuclear research was built in Cambridge, England, in 1930 by John Douglas Cockcroft and Ernest Thomas Sinton Walton. They built an electrostatic machine that was able to accelerate protons to 500,000 electronvolts, but the device was limited by the breakdown of the voltage on the high-voltage electrode, creating huge sparks to ground. Ernest Lawrence saw that, to obtain higher energies, one could build a cyclical accelerator by putting the charged particles between the poles of a magnet, making them turn in circles. Then a hollow electrode driven by an oscillating voltage in resonance with the circular motion of the particles would add energy each time the particles passed through the electrode.

Livingston built the first accelerator to apply this principle, using a hollow D-shaped electrode in a vacuum chamber that fit between the poles of a magnet. With an oscillating voltage of only 1,000 volts, the machine accelerated protons to energies of 80,000 electronvolts. Lawrence was impressed by Livingston's work on the accelerator and offered him an instructorship so that he could stay on at Berkeley to continue the development of cyclotrons. Livingston, who was recently married, readily accepted the offer and began work on a new machine with an eleven-inch magnet. After overcoming severe focusing problems that drove the charged particles into the magnet, he obtained a focused beam of just over one million electronvolts (MeV) in January, 1932. In the next two years, Livingston authored or coauthored more than a dozen papers on the cyclotron and its application to nuclear physics.

After four years in Berkeley, Livingston decided it was time to move on. He felt that his contributions were overshadowed by Lawrence, and he needed to be more independent. He saw an opportunity at Cornell University to work with two well-known physicists, Hans Albrecht Bethe and Robert Bacher, to establish a major research program in nuclear physics. At Cornell, Livingston built a two MeV cyclotron that was the first cyclotron constructed outside Berkeley. In 1936-1937, Bethe, Bacher, and Livingston published a three-part series in the journal *Reviews of Modern Physics* that constituted the most significant review of what was then known of nuclear physics.

In 1938, Livingston moved to the Massachusetts Institute of Technology (MIT) to build a cyclotron for nuclear and medical research. The cyclotron was finished by 1940, and Livingston, finding that he enjoyed teaching and research, stayed on at MIT to use the cyclotron to produce radioactive isotopes for medical use as part of the U.S. effort in World War II. In 1944 he took a leave of absence to go to Washington, D.C., to work with the Navy Department on radar countermeasures for submarines.

After the war, Livingston went back to his position at MIT, but in 1948 he was asked to take another temporary leave to build a large accelerator for the new Brookhaven National Laboratory. The cyclotron had given way to the synchrotron, which uses a ring of magnets (in place of the solid round cyclotron magnets) and magnetic fields and accelerating voltages that vary to counteract relativistic effects. Livingston saw that with this synchrotron idea, he could design a machine for energies above one billion electronvolts. He helped design the accelerator for Brookhaven, but he had to return to MIT before it was completed. The Brookhaven synchrotron, known as the Cosmotron, reached its full design energy in January, 1953: 3.3 gigaelectronvolts (GeV).

Still higher energies were needed to study the fundamental particles within the atomic nucleus, and this would take a huge increase in magnet size and cost because of the defocusing of the beam that had been found with the Cosmotron. After reviewing the Cosmotron magnet design, Livingston suggested that if the gradients in the magnet fields around the ring were alternated, some gradients facing in and others out, the beam would be focused both vertically and horizontally. Cornell, Brookhaven, and the European Nuclear Research Center all built successful proton synchrotrons of about 30 GeV, proving the alternating-gradient principle.

In 1962, Livingston designed, for Harvard and MIT, an alternating-gradient electron synchrotron that accelerated electrons to 6 GeV. This synchrotron, the Cambridge Electron Accelerator, held the record for high-energy electrons until the Stanford Linear Accelerator was built four years later.

DESIGNING THE CYCLOTRON

In 1930, M. Stanley Livingston built the world's first cyclotron at the University of California, Berkeley, under the direction of Ernest Orlando Lawrence. The beam of charged particles was initially too unfocused to be useful, but Livingston solved this problem by removing grids that Lawrence had thought necessary and adding shims to the magnet. He obtained a focused beam of hydrogen ions in 1931 and began using the cyclotron for nuclear research in 1932.

Livingston became expert in designing and building particle accelerators and in solving their problems. In 1948, he designed the magnets for what was then the largest accelerator to be built, the Brookhaven Cosmotron. His design, following the experience with cyclotrons, reduced the magnetic fields outward from the center of the ring for a stable orbit. These gradients kept the beam centered between the poles of the magnets, but they also caused defocusing in the horizontal direction. Livingston saw that at the energies needed to probe deeper into the atomic nucleus, the defocusing of the beam would become extremely large, and the weight and cost of the magnets needed to confine the beam would became exorbitant. He suggested that if alternating sectors of the magnets in the ring had the magnetic gradients reversed, the result would be focusing in both vertical and horizontal directions. Calculations by the theoretician Ernest Courant found that the scheme worked even better than Livingston had estimated. Both horizontal and vertical focusing were improved at all energies.

Livingston found that if the alternating-gradient sectors were spaced evenly around the ring of the accelerator, the beam would oscillate around the central orbit. If the magnetic gradients were made stronger and the sectors were spaced more closely, the size of the oscillations would be reduced, and a tighter beam could be obtained. The size of the apertures in the magnets could then be reduced, resulting in a large reduction in the size of the magnets and thus a reduction in cost. This was a revolution in accelerator design. In an alternating-gradient machine ten times the energy of a conventional weak-focusing accelerator such as the Cosmotron, only twice the amount of iron would be needed for the magnets. In larger rings of alternating-gradient magnets, higher energies could be attained without limit. All high-energy accelerators now use alternating-gradient focusing.

In 1966, the U.S. Department of Energy decided to build a national accelerator laboratory outside Chicago. Livingston was recruited to be an associate director to help set up the Fermi National Accelerator Laboratory (known as Fermilab) and to design a 200 GeV proton synchrotron. The machine was completed successfully after Livingston's retirement from the lab, and its energy has been continually upgraded since that time. It became the highest-energy proton accelerator in the world.

Livingston retired from Fermilab in 1970, and he and his wife Lois moved to Santa Fe, New Mexico, where they built an adobe house that they designed themselves. In retirement, Livingston consulted occasionally for the Los Alamos Scientific Laboratory and became increasingly involved in promoting international scientific cooperation through the Federation of American Scientists. He received many honors during his career, including election to the National Academy of Sciences in 1970. He was a recipient of the U.S. Department of Energy's Enrico Fermi Award in 1986, but after an unsuccessful operation for cancer, he died on the day the award was to be presented to him.

IMPACT

The inventions of the cyclotron and the alternating-gradient synchrotron had revolutionary impacts on modern science and medicine. Livingston became the world's expert in designing and building high-energy charged particle accelerators, and from his first project, building the pioneering cyclotron with Ernest Lawrence, he systematically added improvements and built higher-energy machines.

The first cyclotrons were built for research on the atomic nucleus, but these devices came to be used for many other purposes as well. The more than two hundred cyclotrons in use worldwide are employed in atomic and solid-state research, in studies of radiation damage, and in the radiocarbon dating of archaeological materials. In the field of medicine, cyclotrons are used for the production of radioactive isotopes for imaging and diagnosing cancers as well as for the direct treatment of cancer by radiation.

In high-energy physics research, Livingston's invention of alternating-gradient focusing and the accelerators that were designed and built using this principle have been the main tools used by scientists seeking to understand the atomic nucleus and the subnuclear particles within it. Without these accelerators, little would be known of the primary building blocks of the universe, the quarks and nuclear forces.

Lawrence and Livingston's pioneering work with particle accelerators opened the era of big science. Prior to their work, nuclear research was tabletop science carried out by a few people using naturally occurring radioactive sources. The huge accelerators that have been built since Livingston's work began are staffed by hundreds of people and are used by experimenters from around the world.

—*Raymond D. Cooper*

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See also: Luis W. Álvarez; Walther Bothe; Ernest Orlando Lawrence; Leo Szilard; Ernest Thomas Sinton Walton.

AUGUSTE AND LOUIS LUMIÈRE

French photographers and filmmakers

Auguste and Louis Lumière invented the cinématographe, a portable camera that also printed and projected films; established several film conventions; and by charging admission for their screenings effectively began the motion-picture business.

AUGUSTE LUMIÈRE

Born: October 19, 1862; Besançon, France
Died: April 10, 1954; Lyon, France
Also known as: Auguste Marie Louis Lumière (full name)

LOUIS LUMIÈRE

Born: October 5, 1864; Besançon, France
Died: June 6, 1948; Bandol, France
Also known as: Louise Jean Lumière (full name)
Primary field: Photography
Primary invention: Cinématographe motion-picture camera

EARLY LIVES

Auguste Marie Louis and Louis Jean Lumière (loo-myehr) were the sons of Antoine Lumière, a sign painter who progressed to painting portraits and then to producing photographic supplies. His two sons attended La Martinière, Lyon's largest technical school, and they went to work for their father while they were still in their teens. In 1881, when he was only seventeen, Louis, the more creative of the brothers, produced a high-quality photographic plate that became so popular that it enabled him to build his own factory to manufacture the plates. His was the second-largest photographic company in the world; only Eastman Kodak was larger.

LIVES' WORK

Although the Lumières are credited with inventing the motion-picture camera, their invention built upon the work of many other inventors. Ever since the first photograph was taken in 1826 by another Frenchman, Nicéphore Niépce, inventors tried to find ways to show pictures in motion. Eadweard Muybridge was one of the first, and his photographs of horses in motion provide a milestone in film history. Étienne-Jules Marey's chronophotograph was another step, as was the camera invented by Louis Le Prince, whose invention was a forerunner of the Lumières' camera. However, before Le Prince could market his camera, he mysteriously disappeared. Thomas Alva Edison, who had invented the phonograph, and William Dickson, one of his employees, invented the first movie camera and the first projector.

Hoping to capitalize on the success of their popular and profitable kinetoscope, Edison and his firm took their product to Paris, where Antoine Lumière saw a demonstration. He told his sons that a fortune could be made if they could devise a less bulky and improved movie camera. Auguste tried but was unsuccessful. After several attempts, Louis was successful, and the cinématographe was born. The camera, which also served as the printer and projector, was smaller than Edison's massive kinetograph so that it was portable enough to be carried to any place the brothers wanted to shoot a film.

Auguste (left) and Louis Lumière. (Time & Life Pictures/Getty Images)

The Cinématographe

According to film historians, Louis Lumière, who was an insomniac, got the idea for the cinématographe one sleepless night when he was pondering how to make the film in a camera advance. The operation of the sewing machine provided him with a model. The sewing machine holds the fabric still while the needle and thread make a stitch, then advances the fabric and holds it while the next stitch is made. In like manner, the shutter of a still camera opens, admitting light onto the film behind the lens, then closes to prevent additional light from overexposing the film. The problem of how to advance the film for successive images was solved by putting perforations on the edges of the film and by having claws or gears engage the perforations. After the film moved, the claws released, holding the film still for the next shot. After the shutter closed, the claws reengaged the film, moving it forward and then releasing it for the next shot. The shots or frames were separated by black bands that occurred because of the lack of light. When the film was played, the frames appeared in quick succession, so quickly that the human eye could not distinguish between the individual frames and perceived the slight differences as motion. The stop-and-go sequence, or intermittent motion, remains one of the basic principles of cinematography. Auguste and Louis Lumière used the negatives to print a film, which consisted of images interspersed with black bands.

The same camera could also be used to project the film, a real advantage over Thomas Alva Edison's kinetoscope, which required an additional projector and provided a film that could only be used by one person at a time. Intermittent motion was also used in projecting the brothers' films. They had a light source behind the projector lens. As a frame appeared in front of the projector lens, it was held for a moment while the shutter opened, then closed as the film advanced to the next frame, when the shutter would open again. The opening and shutting occurred at the rate of sixteen times per second, just as the film had been shot at sixteen frames per second. The light, which went on and off as the images and bands alternated, produced a flickering effect. (Occasionally, people refer to films as "flickers" or, more frequently, as "flicks.") Technical improvements have since almost entirely eliminated the flickering. The brothers' motion-picture camera, which also could print and project film, represented the most important advance in film history because the projection of a film to paying audiences has made the motion-picture industry what it is today.

The other advantage the cinématographe had over the kinetoscope was that Edison's machine only allowed for one viewer at a time; the brothers' machine could be shown to an audience. They patented their machine on February 13, 1895, and only a month later shot their first film, *La Sortie des usines Lumière* (*Workers Leaving the Lumière Factory*).

Interested in marketing their machine, they took it to Paris, where they gave private screenings to members of the Society for the Encouragement of National Industry and to the French Photographic Society. The brothers quickly saw that they could benefit not only by selling their machines but also from holding public exhibitions and charging admission. Louis shot most of the films; Auguste, who was more of a manager, probably shot just one. Once they had shot ten films—including the factory film, *Le Repas de Bébé* (1895; *Feeding the Baby*), and *Le Jardinier* (1895; *The Gardener*), also known as *L'Arroseur Arrosé* (*The Waterer Watered*)—the first public showing (admission was one franc) occurred at the Grand Café, which Auguste had rented for the occasion. Although the first audience was small—some thirty-five people—word spread rapidly, and soon the brothers were taking in two thousand francs a week from multiple showings of the ten films. Lumière cameramen were recruited to shoot additional films all over the world. (Eventually, there were more than fourteen thousand films in the catalog they published in 1898. Fewer than fifty were shot by the brothers.) The films were home movies, travelogues, and "soft news," recording events such as floods or fires.

The Lumières' biggest market became the United States, but Edison's influence with the U.S. government caused legal problems for the brothers, and there were many other competitors as well. By the fall of 1897, Lumière cameramen had left the United States, and after 1900, the year the Lumières sold their movie rights to Pathé, the brothers were out of the movie exhibition business. In 1900, they did design a huge screen (99 by 79 feet) for the Universal Exhibition in Paris and screen some of their films. Three years later, they patented Autochrome Lumière, a kind of color film for still photography, and in 1907 they created the autochrome plate, the first practical color photography process, one that was used until the 1930's, when it was replaced by a subtractive color process. Louis was awarded the Progress Medal of the Royal Photographic Society in 1909 and stayed with the photography business, while Auguste turned his energies to biology and medicine. Auguste was a pioneer in the treatment of wounds and held more than one hundred patents, one of which was for the homonoid forceps. In 1915, he created tulle gras, a sterilized treatment bandage.

IMPACT

Although the Lumières' invention was certainly not the first movie camera, theirs was the first to become commercially viable, due to the fact that the brothers' company had the financial support to make the machines, to send crews around the world to make their films, and to screen the films (the same cameras shot and screened the films). The Lumières are regarded by most film historians as the fathers of the nonfiction film or the documentary, just as Thomas Edison is the father of the fiction film. Moreover, the Lumière films established the motion-picture camera as a still camera with an emphasis on composition and possessed a sense of a story line with beginning, middle, and end. Despite the rivalry between the Lumière and Edison filmmakers, the two companies did borrow from each other—the most celebrated case being Edison's *Washday Troubles* (1898), a takeoff of the Lumières' *L'Arroseur Arrosé*.

The success of the brothers' films made them the most important men in the film world. By making films all over the globe, they enabled their film patrons to "visit" places they could never visit. Their films also were the first to be screened in India, Japan, and other countries, and, of course, the Japanese and the Indians have become major players in the film industry. Gerald Mast and Bruce Kawin have called the Lumière brothers the "Johnny Appleseeds" of the film world. The practices and conventions they established became the standards for the industry: the film width at 35mm; the exposure rate of sixteen frames per second (speeded up for better sound only when the "talkies" were introduced), which Edison switched to; and the name of their machine, the cinématographe, which persists in the form of "the cinema" and "cinematography" (shooting the film).

—*Thomas L. Erskine*

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See also: Louis Jacques Daguerre; George Eastman; Thomas Alva Edison; Leopold Godowsky, Jr.; Edwin Herbert Land; Gabriel Lippmann; Leopold Mannes; Nicéphore Niépce.

John Loudon McAdam

Scottish businessman

McAdam's method of road construction and maintenance vastly improved roads and highways at the start of the nineteenth century, facilitating the transport of both goods and people and making a decisive contribution to the Industrial Revolution.

Born: September 21, 1756; Ayr, Ayrshire, Scotland
Died: November 26, 1836; Moffat, Scotland
Primary field: Civil engineering
Primary invention: Macadamization

Early Life

John Loudon McAdam was born in Ayr, in southwest Scotland, on September 21, 1756, the second son and youngest of ten children of James McAdam, baron of Waterhead, and Susanna Cochrane, niece of the earl of Dundonald. Through his parents, young McAdam was connected to many of the leading Scottish families of his time and was considered a gentleman. He greatly valued this social standing in later life, as it imparted respect upon his somewhat modest occupation as a road surveyor. For much of his childhood, like many boys of his age, his winters were spent attending the parochial school in nearby Maybole and his summers were filled with explorations of the surrounding countryside.

Following his father's death in 1770, McAdam, at the age of fourteen, was sent to New York to the care of his uncle, William McAdam, a powerful merchant and Loyalist who had prospered in the New World. Uncle William first employed his nephew in his counting house, but soon the young McAdam went into business for himself. Despite his youth he accumulated a small fortune. In March, 1778, McAdam married Glorianna Nicoll, the daughter of a prominent and wealthy landowner whose family also was loyal to the British. Because McAdam had served in the British reserve forces during the American War of Independence, the victory of the colonies gave him no choice but to return to Scotland in 1783. He returned as a wealthy man and was accompanied by his wife and two children. The family would grow in the following years and settle in Ayrshire, where McAdam spent his childhood, on an estate purchased at Sauchrie in 1785.

Beginning in 1787, McAdam was a trustee of the Ayrshire turnpike roads system. In later life, he revealed that it was as a trustee that he was first exposed to the wasteful expenditure of public funds for maintaining the road system. He had soon determined to improve road construction, administration, and repair.

Life's Work

During his period at Sauchrie, McAdam again went into business, this time with his eccentric cousin, Archibald Cochrane, whose interest in extracting tar from coal led him to found the British Tar Company. Cochrane hoped to supply tar for the shipping industry, which needed the product to seal ships' hulls. McAdam held interests in local mills and iron works, became a plant manager, and ultimately bought the tar company. Several of his other business ventures went awry, however, and McAdam was almost ruined financially.

In 1798, McAdam sold his estate, settled with his creditors, and left Scotland for England. Settled in Bristol in 1801 with his family, McAdam began his first investigations into road construction and administration. He later claimed (in evidence presented to the British parliament in 1823) that between 1798 and 1814 he had traveled approximately thirty thousand miles in examining almost every major road in Britain. He inspected their condition and construction and questioned those who worked and traveled on the roads. (Because this project was conducted at his own expense, McAdam had sought some recompense from public funds.) By 1811, McAdam realized that the problem of road construction and maintenance was not about making vehicles adapt to roads but about making roads suitable for all vehicles. Furthermore, multiple laws regulated the manufacture of vehicles, but no laws regulated road construction and maintenance.

Although McAdam believed that road-makers and road-repairers were responsible for many of the failings of the roads system, largely from ignorance, he professed particular contempt for road surveyors. He was so adamant about change that in 1816 he become a surveyor himself. At the age of sixty, he became general surveyor of the Bristol roads system. His first goal was to eliminate corruption and waste (Bristol Turnpike Trust, the largest in the country, had debts of thousands of pounds) and restructure the workforce. McAdam mistrusted many of those then employed as surveyors, so he removed those he considered most incompetent and raised the salaries of those he retained.

Prior to McAdam's intervention, the typical method of repairing a road was to dump large stones on a road's surface to fill holes and ruts; it was believed that the weight of passing traffic would flatten the stones into some kind of consistent surface. McAdam, however, knew that these stones would not be forced together by a passing carriage wheel; instead, the stones would be displaced. McAdam's idea was to break the surface stones to a size smaller than the average vehicle wheel's width (typically about one inch). These smaller stones would consolidate to form a smooth, hard, and durable surface. The materials needed were already at hand, in the form of the oversized rocks of the previous repairs.

Soon, "macadamization," as McAdam's method became known, afforded better roads for less cost. Turnpike trusts in other areas were keen to implement the system. McAdam was consulted extensively and ultimately held seventeen other surveyorships from southwest England to Perthshire in the heart of Scotland. He often recommended his sons for these surveyor positions; eventually, eleven individuals from three generations of his family were employed in a similar capacity over subsequent decades. The family consultancy grew, and much of England, Wales, and Scotland would reap the benefits of improved roadways. The success of the McAdams was partly facilitated by powerful aristocratic patrons, many of whom were friends of the family. Nevertheless, McAdam encountered much resistance to change, professional jealousy, and even ridicule throughout his career.

The last years of McAdam's life were no less eventful than earlier decades. His wife died in 1825; he was remarried in 1827, to his wife's cousin, Anne De Lancey. They settled in Hoddeston, Hertfordshire, close to his friend, George Allen, whose factory made many of the implements used on the turnpike roads. McAdam remained active and engaged in the activities of the various trusts that retained his services. He spent the summers of these years in his native Scotland, returning south in late fall. He died on November 26, 1836, at Moffat in Ayrshire, following an illness.

MACADAMIZATION

John Loudon McAdam realized that small, suitably sized pieces of broken stone could form the base of a strong and durable roadway because so much natural friction and interlocking occurs between individual pieces of such stones. His roads consisted of a base eight to twelve inches thick, applied in two layers, and composed of angular, hand-broken stones no larger than three inches each. A third, surface layer comprised even smaller stones, no bigger than one inch, to a maximum depth of around two inches. All of this was laid on the natural formation, which was cambered and had side ditches for drainage. Ensuring that the ground was well drained was crucial. A properly maintained and drained road, McAdam asserted, could support any load: indeed, his roads could support over one hundred pounds per inch of tire width—around twice what his contemporaries could achieve.

McAdam's methods were not entirely new. Pierre-Marie-Jérôme Trésaguet in France and Thomas Telford in Britain had built many miles of roads on the basis of similar techniques, but they demanded small surface stones placed on a base of large, hand-crafted blocks. There is no suggestion that McAdam copied these earlier methods, but rather that he simply observed empirically that his system of smaller stones was the best and certainly the most cost-effective. Telford's roads, for example, were claimed to be more robust and durable than those of McAdam, but they also were far more expensive.

McAdam's method of road construction substantially advanced road transportation in Britain before the coming of the railway age. Indeed, the noun "macadam" and the verb "macadamize" had entered the British vocabulary by around 1825, as more and more miles of roadway were improved to his specifications. McAdam's reputation grew as both employers and the public saw the benefits of his system. Later, when fast-moving motor vehicles appeared, they produced large amounts of dust from such roads and ultimately could cause the surface stones to separate. An alternative means of surface binding using tar was developed, creating "tar-bound macadam" ("tarmacadam" or "tarmac"), very similar to modern asphalt surfaces. Although many roads have now been resurfaced with asphalt or concrete, McAdam's name and work survive today, and the word "tarmac" is still used to describe the paved area of airports.

IMPACT

McAdam, a key player in improving British highways, was instrumental to the dramatic advances of the Industrial Revolution. With the dawn of the Industrial Revolution in the late eighteenth century, it became increasingly evident that good transport routes were essential to the movement of raw materials and manufactured goods, as well as people and services. Most of Britain at the time was poorly served by the road network, and much of Scotland was effectively isolated by lack of infrastructure. With the new roads, journey times were dramatically reduced (often more than halved), increasing the flow of goods and services, including the mail, at a time when better communication was becoming vital to progress.

McAdam's system had both human and humane benefits. Although manual work on the roads was a despised form of labor, unemployment was high at the time. The labor-intensive breaking of stone required many workers, providing much-needed employment, particularly for the poor. Horses also benefited from the new roads: No longer required to drag coaches over crude, rutted roadways, horses suffered fewer short- and long-term injuries and hence would often live longer than the earlier average of only four years.

Given that his methods also relied upon careful oversight and the management of day-to-day expenses, McAdam can be considered one of the earliest modern professional managers. His early business ventures with the British Tar Company also make him a pioneer of modern chemical manufacturing.

McAdam was an advocate as well as an engineer, actively promoting his methods before Parliament and in several publications. In pressing his belief that there should be more centralized control over roads, he was not only seeking civic consolidation but also endorsing public policy. His plans would not be widely realized for several decades, by which time macadamization was common practice, not only in Britain but also around the world.

—*Thomas D. McGrath*

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See also: Joseph Monier; John Augustus Roebling.

CYRUS HALL MCCORMICK

American machinist and agriculturist

McCormick invented the first successful reaping machine, which combined all the steps that earlier harvesting machines had performed separately. His invention led to increased crop production, lower labor costs, the development of the Western frontier in the United States, and the country's evolution from an agrarian to an industrial society.

Born: February 15, 1809; Rockbridge County, Virginia
Died: May 13, 1884; Chicago, Illinois
Primary fields: Agriculture; manufacturing
Primary invention: Mechanical reaper

EARLY LIFE

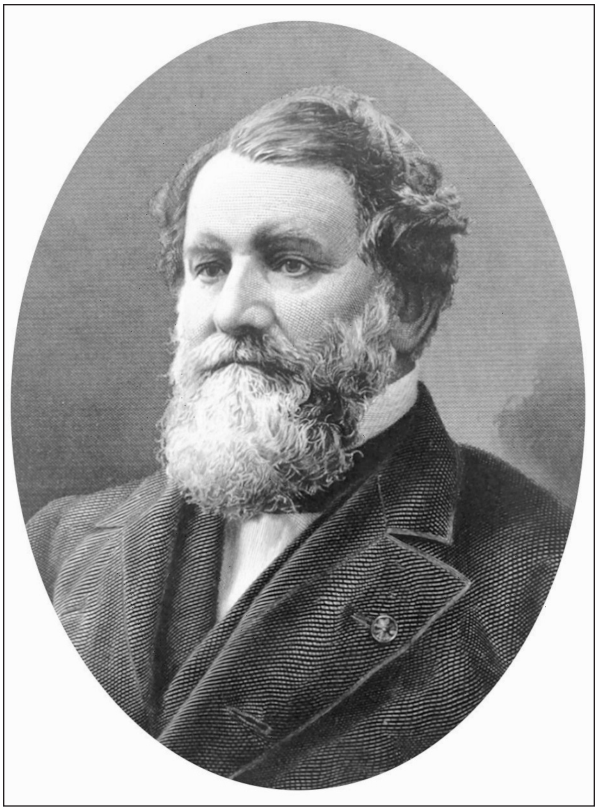
Cyrus Hall McCormick was born to Mary Ann Hall and Robert Hall McCormick in Rockbridge County, Virginia, on the family farm in 1809. At the time of his birth, he was presented with a two-year-old slave named Jo Anderson. Jo would be with him throughout his childhood, but McCormick would have few other close friends growing up. He worked on the family farm, known as Woodbridge, and attended a rural school when time permitted. At school, he learned the basics of reading, writing, geography, and religion. He may have had a special tutor for surveying and mathematics.

Although McCormick became known as an innovator, his childhood environment was traditional. The farm and the church were two focal points, and he was raised in a strict Presbyterian home with daily Scripture readings. He was religiously active throughout his life, including involvement with local churches and making contributions to Presbyterian churches and seminaries. Coming from a slave-owning family, he also strongly defended the institution of slavery up to and throughout the American Civil War. He would use his ownership of the *Chicago Times* to promote pro-Southern ideas.

McCormick's father, Robert, was interested in the innovative and mechanical side of farming. Like his father, the younger McCormick was drawn to the workshop more than the fields. Around the age of fifteen, McCormick invented a lightweight grain cradle and a hillside plow. His father built mills on his and his three sons' adjoining farms and three other sawmills and two flour mills. He made a hemp brake, a clover sheller, a thresher, and a plow in his workshop. He also had worked intermittently in the farm's blacksmith shop on a horse-drawn reaper but was unable to produce a practical machine. A successful reaper had to separate, cut, and deposit stalks to avoid any shelling of kernels. It had to prevent entanglement and ensure the stalks stayed parallel for curing. It also had to cut parallel with the ground, even if that ground was irregular. Robert abandoned the project in 1831. McCormick picked up the project that same year and succeeded with his own invention, the first practical mechanical reaper. He was just twenty-two years old.

LIFE'S WORK

Cyrus Hall McCormick's invention addressed a longstanding problem in farming and agriculture: the need to harvest at just the right time. This need to pinpoint a harvest time made it difficult to cultivate large crops, which had to be gathered en masse by many laborers. At harvest time, labor became scarce and expensive. Before the invention of the reaper, only three acres per day could be



Cyrus Hall McCormick. (Library of Congress)

The Mechanical Reaper

In the early nineteenth century, harvesting required a large amount of labor to get everything harvested in time. The often scarce labor was expensive as well. The reaper offered the hope that production would no longer be limited by the amount of labor available. Several people, including Cyrus Hall McCormick's own father, had tried unsuccessfully to invent a working harvest machine.

The essential elements in McCormick's reaper included a reciprocating knife (which moved back and forth), against which the grain stalks fell; fingers or guards for the knife to hold the stalks during the cutting action; a horizontal and adjustable rotating reel to pull the stalks into the machine; a master or main wheel that turned directly behind the horse and supplied power to the reel and knife; a forward side draft (the horse walked in front of the wheel and to the side of the machine so the knife could cut the standing grain); a divider to separate the grain to be cut from that to be left standing; and a platform or grain deck flexibly attached to the master wheel to accommodate irregular ground. The machine required two workers to operate and incorporated all the mechanical principles of modern harvesting machinery.

McCormick's reaper could cut as much as in one day as four to five laborers with cradles or twelve to sixteen laborers with reaping hooks. His early machines required only two people to operate (one to ride the horse and one to rake the cut grain from the platform to the ground). Other workers could gather the cut grain into bundles and tie them with twists of grain. The reaper also lessened waste. It could save one bushel of wheat per acre, ordinarily lost by shelling when workers used the cradle. Eventually, McCormick would eliminate the need for the additional workers to bind the grain when he invented a self-binder in 1876 and a twine binder in 1881. A farmer could now complete the harvest on his own by driving the reaper (with a driver's seat that McCormick added) and taking care of the horse or horse team.

harvested. With the reaper, farmers could harvest fifteen acres per day with just two people to operate the machine.

McCormick's first machine was rudimentary, but he developed it more fully after the first test showed that it worked. He conceived plans for the reaper, built and tested it, and then improved it for public trial. He immediately began to demonstrate his reaper with practical tests in the field. However, he did not seek a patent until 1834. This allowed him to use the reaper in three successive harvests under a variety of conditions and then try to perfect it. Word about the machine spread, however, and its success was noted in agricultural publications as early as 1832. McCormick continued to make several experimental machines in his shop. The machines were not manufactured commercially until 1840.

From 1837, the year a family business failed, until his death in 1884, McCormick focused on the reaper—its improvement, manufacture, and marketing. He had little capital to begin his work, but he produced his machines nonetheless; he sold his first two reapers in 1840. All materials and completed machines had to be transported over land because there were no railroads or canals nearby.

To market the machine, McCormick began to travel and do field trials. He showed that while the reaper was helpful in Virginia, it was essential in Ohio, Illinois, and the plains. In 1847, the McCormick Harvesting Machine Company moved to Chicago. Within one year, the company had 120 employees and produced 450 machines, making it Chicago's largest employer.

McCormick continued to work on improvements to the reaper. His success brought rivals, such as Obed Hussey, who had patented a reaper before McCormick. However, McCormick had successfully demonstrated his machine two years before Hussey demonstrated his in 1833. When McCormick's basic patent expired in 1848, he applied for an extension. However, rival companies blocked the extension, even though the U.S. patent commissioner testified to the U.S. Congress that the invention of the reaper was as important to agriculture as the spinning jenny and power loom had been to the textile industry. In the 1850's, McCormick sued another rival, John Manny, for patent infringement but lost his lawsuit. In 1860, McCormick once again unsuccessfully applied for an extension of the patent.

The loss of the suit and the denial of patent extensions cost McCormick's company much money, but not its competitiveness. McCormick received new patents as he continued to improve the machine, developing combined machinery for reaping and mowing, seats for the driver and raker, and an all-metal main wheel. His later machines also cut wider swaths. He demonstrated his mechanical reaper at the 1851 Crystal Palace Exhibition in London. He was awarded for his invention, the first of many European awards and gold medals. In 1858, he patented his "Automatic Self-Rake Reaper," which needed one person to operate.

Despite many setbacks during the years, including more legal battles and the destruction of his factories in the Chicago fire of 1871, McCormick continued to invent new equipment. His "Marsh Type Harvester" had an elevator and binding platforms. His 1876 "Harvester and Binder" was the first practical self-binder built. It cut and bound grain in a single operation. The last major improvement came in 1881 with the "Harvester and Twine Binder," which bundled with twine rather than wire.

McCormick died in Chicago in 1884. The town was sixty times the size it had been when he moved there in 1847. His factories had produced several million harvesting machines. In 1902, the McCormick Harvesting Machine Company, under the direction of McCormick's grandson, merged with four smaller harvesting-machine manufacturers to form the International Harvester Company.

IMPACT

McCormick's Virginia reaper, as his invention was first known, and the mechanical revolution it sparked transformed American agriculture by requiring fewer and fewer people to produce more and more crops. The reaper also helped form the Western frontier, and many claim it had a part in the outcome of the Civil War. The reaper, which allowed farmers to fight without causing a severe drop in agricultural production, may have contributed to the success of the Union army.

U.S. secretary of state William H. Seward claimed that the reaper extended the frontier thirty miles per year, making it possible for agricultural production to keep pace with urban growth in the West. The U.S. population doubled between 1840 and 1870. Farms had to produce more to meet the demands of the new populations. In 1831, 90 percent of the population farmed to meet the nation's needs. At the end of the twentieth century, less than 2 percent of the population was directly involved in farming, which meant high demand for the remaining farmlands.

McCormick's invention of the reaper also encouraged the invention of other agricultural machinery that reduced labor while increasing production. His company offered easy credit to enable farmers to pay for machines from increased harvests. Its salesmen also made door-to-door sales calls. The company was one of the first to offer a fixed price and performance guarantees. The company's success in Europe after 1851 helped to push the United States to export manufactured goods as well as raw materials, and it helped to transform the country from an agrarian society into an industrial world power.

—Linda Eikmeier Endersby

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See also: Andrew Jackson Beard; John Deere; Thomas Jefferson; Jethro Tull.

Elijah McCoy

Canadian American mechanical engineer

McCoy invented more than fifty different devices, most of which improved the operation of locomotives. Many of his inventions automatically dispensed oil to lubricate the moving parts of the locomotive, reducing friction and helping the train run more smoothly.

Born: March 27, 1843; Colchester, Ontario, Canada
Died: October 10, 1929; Eloise, Michigan
Primary field: Railway engineering
Primary invention: Automatic lubricator

Early Life

Elijah McCoy (ee-LI-juh mih-KOY) was born in 1843 to George McCoy and Mildred Goins McCoy. Many sources give his birth date as May 2, 1844, but the date of March 27, 1843, appears on his death certificate. He was the third child of the McCoys; they had nine more children.

George and Mildred McCoy had lived in slavery in Kentucky until 1837. That year, they escaped to freedom on the Underground Railroad, the network of hidden paths and safe houses that allowed African Americans to flee to free soil. Like many slaves who had escaped along this system, they settled in Canada, which had no slavery. George McCoy joined the Canadian army and, after completing his service, was rewarded with 160 acres of land in Colchester, a village southeast of Windsor and on the shores of Lake Erie.

While helping out on his parents' farm, Elijah McCoy completed his elementary schooling and also attended a mechanical school. He apparently showed some aptitude for mechanics, and at age fifteen he was sent to Edinburgh, Scotland, to work as an apprentice to a mechanical engineer. McCoy's apprenticeship lasted five years. He returned to North America in the mid-1860's, trained as a master mechanic.

The family returned to the United States, settling in Ypsilanti, Michigan, a small city near Detroit. The Michigan Central Railroad was based in that city. McCoy, with his training as a mechanic, hoped to find work with it.

McCoy was hired by the railroad, but neither as a mechanic nor as an engineer. He was hired as a fireman, whose task it was to shovel coal into the firebox of the locomotive, fueling the fire that produced the energy to move the train. Racial prejudice might well have played a role in McCoy's being thus underemployed.

Life's Work

In a steam-powered locomotive, steam produced by the train's boiler enters large cylinders. The buildup and loss of steam pressure drives pistons to move in and out of the cylinders, and that motion moves the wheels of the train. These moving parts operate under extremely high temperatures. They must be lubricated to prevent the high temperatures and friction from destroying them.

As early as 1850, British inventors had created devices to provide a steady stream of oil to lubricate these parts as they moved. At least one of these devices was used not only in railways there but also elsewhere in Europe and in the United States. It is not clear if such devices were part of the locomotives on which McCoy labored. That is likely, however, as he called his first invention an "improvement in lubricators for steam-engines."

Working in a makeshift shop when he could find the time, McCoy spent two years developing a system that would regularly distribute oil onto the moving parts to lubricate them. He completed his work in the summer of 1872 and submitted his first patent application to the U.S. Patent Office. On July 23, 1872, he was awarded the patent. As he would do with many of his later inventions, McCoy assigned the rights of patent to both himself and another person who was, perhaps, an official of the railroad. (Companies often require employees who obtain a patent to assign the rights to the company.)

McCoy's new lubricator was the first of more than fifty patents he would eventually hold. The second came just two months after the first, when McCoy patented an improved model of his self-regulating lubricator. In all, nearly three dozen of McCoy's patents were lubricators that could be used on trains. His lubricating devices also had applications in other steam engines, such as those driving steamships. Among his few nonrailroad inventions were an ironing board (patented in 1874), a lawn sprinkler (1899), and treads for tires (1915).

As railroad technology advanced, McCoy kept abreast of the changes and invented new devices suited to the newer equipment. In 1872, George Westinghouse invented a new railroad braking system called the air brake. More reliable than earlier railroad brakes, the air brake made it easier to stop trains that were larger and heavier, and that ran faster, than before. McCoy invented several lubricating devices that oiled these powerful brakes, helping them operate smoothly.

Another change came in the early 1900's, when engineers developed so-called superheater steam engines. In these engines, the steam produced by the boiler is heated again, which enables it to deliver even more energy when released. Superheater locomotives generated much higher temperatures, which made lubricating them both more important and more difficult. McCoy worked on developing a graphite lubricator to help meet this challenge. Graphite—the same material found in pencils—is a solid lubricant that works very well at high temperatures. McCoy's device suspended graphite in lubricating oil so that the solid would not cause clogs in the machinery. McCoy patented his first graphite lubricator in 1915. He followed over the next few years with improved versions.

McCoy left the Michigan Central Railroad in 1882 and moved to Detroit. There, he worked on his inventions and as a consulting engineer for a company that made lubricators. In 1920, when McCoy was in his mid-seventies, he launched his own company, the Elijah McCoy Manufacturing Company, based in Detroit. The company made lubricators and other devices of McCoy's design. He patented his last four lubricators during the 1920's.

The remaining years of McCoy's life were marred by tragedy. He had married his first wife, Ann Elizabeth Stewart, in 1868, but she had died in 1872—the year of McCoy's first patent. He married Mary Eleanor Delaney the following year, and they lived more than fifty years together. Soon after the McCoy company was founded, however, McCoy and his wife were in an auto accident. Mary McCoy never fully recovered from her injuries and died in 1923. McCoy himself weakened, in part because of injuries incurred in the accident. In addition, he suffered from high blood pressure and, eventually, senile dementia. In 1928, as a result of senility, he was placed in an asylum in what is now Westland, Michigan. The following year, he died.

IMPACT

McCoy was a trained engineer and mechanic who invented several lubricating devices. Some popular writers call him the "father of lubrication," but other sources dismiss that claim. Still, McCoy can be credited with creating valuable devices that helped railroad locomotives and air brakes function well.

McCoy is often credited in popular literature as the origin of the term "the real McCoy," said to be a tribute to the reliability of the device he first invented. That claim appears unjustified. Sources do not offer documented evidence of its truth. Also, language scholars say that the origin of the term is unknown. It is variously ascribed to a boxer, a liquor distiller, and several other characters. Also, the phrase appears to predate McCoy and his invention.

The lack of justification for these claims does not diminish McCoy's achievement. That he was an African American living in a predominantly white society that often showed little respect or regard for blacks makes his accomplishments the more notable. Late in his life, he held more patents than any other African American inventor.

—Dale Anderson

MCCOY'S FIRST LUBRICATOR

In the late nineteenth and early twentieth centuries, before air and automobile technology, trains transported goods and people across the United States, and their smooth operation was key to keeping the U.S. economy running. Elijah McCoy's first invention was a type of automatic lubricator that used the steam produced by the train's engine to force oil from a holding cup through a channel to the cylinder. This device is called a hydrostatic lubricator because it relies on pressure to maintain the lubricant in place between the working parts.

The lubricator is in the form of a lidded cup that sits on top of a cylinder near one end. At the bottom of the cup is a stem, which is the piece that attaches to the cylinder. Running through the center of the cup and into this stem is a tube with valves at the top and bottom. The tube does not fill the stem completely. When steam pushes the piston forward in the cylinder, some steam escapes around the piston to the head of the cylinder. Some of this steam, in turn, enters the tube of McCoy's lubricator. That steam pushes open the valve as it rises into the cup. Since the valve is open, oil flows through its opening into the stem. It fills the space between the outside of the tube and the inside of the stem and flows down into the cylinder, where it can keep the piston lubricated.

The steam entering the lubricator cup collects and condenses, or cools. As it changes to water, the oil remaining in the cup rises above it, since water is denser than oil. As a result, the oil is always high enough that it is in contact with the top of the stem and tube apparatus.

McCoy placed a faucet with another valve at the bottom of the lubricating cup. When the cup was filled with water, the operator could simply open the faucet to drain this liquid. A thumbscrew on the cup's lid could then be turned to remove the lid and refill the cup with oil. The lubricator was then ready to dispense oil automatically again once the steam engine of the locomotive got under way.

FURTHER READING

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Sluby, Patricia Carter. *The Inventive Spirit of African Americans: Patented Ingenuity*. Westport, Conn.: Praeger, 2004. Sketches McCoy's life and work. The book's illustrations include McCoy's design patent for a lawn sprinkler, in the shape of a turtle. The list of patents in the back of the book collects McCoy's patents by name, making them easier to study than the list in Brodie's book.

See also: Edward Goodrich Acheson; Andrew Jackson Beard; Peter Cooper; George Mortimer Pullman; George Stephenson; Richard Trevithick; George Westinghouse; Granville T. Woods.

PAUL B. MACCREADY

American aeronautical engineer

MacCready made human-powered flight a reality with his Gossamer Condor and Gossamer Albatross aircraft. Although many of his inventions were not commercially viable, they advanced environmentally responsible technologies while serving as symbols of what can be achieved through creative thinking.

Born: September 29, 1925; New Haven, Connecticut
Died: August 28, 2007; Pasadena, California
Also known as: Paul Beattie MacCready, Jr. (full name)
Primary field: Aeronautics and aerospace technology
Primary inventions: Gossamer Condor; Gossamer Albatross

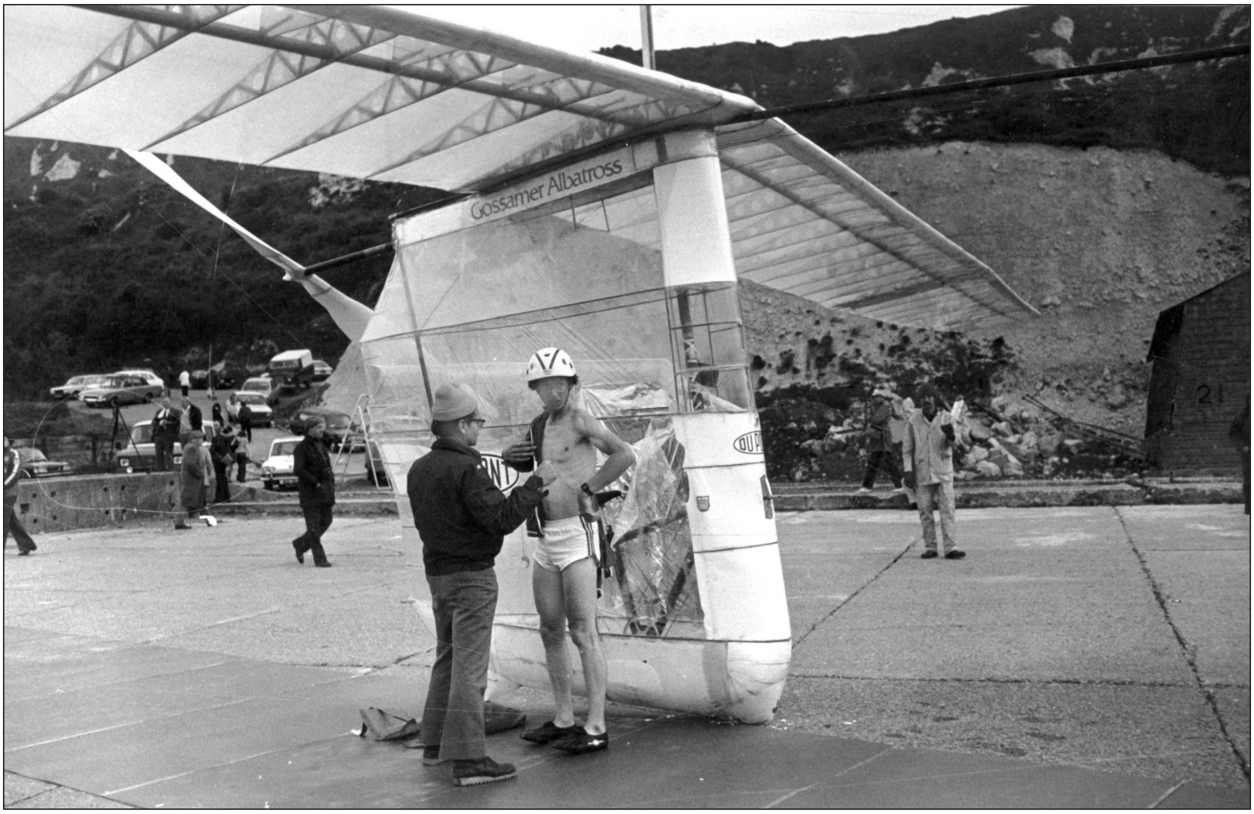
EARLY LIFE

Paul Beattie MacCready, Jr., was born in 1925 in New Haven, Connecticut. The youngest of three children and the only son of a successful doctor, MacCready showed an early intellectual curiosity and creativity. A boyhood interest in butterflies and moths grew into a love for building and flying model aircraft, a passion that would remain with him throughout his adult life.

After creating his first model airplanes from kits, he began designing his own aircraft models from scratch. Curious about unconventional designs, he experimented with model helicopters, ornithopters (which employ flapping wings to support and propel them in flight), and autogyros (which use a motor-powered propeller for thrust and an autorotating rotor for lift). He built indoor models, outdoor models, and models that could take off from water, propelling his creations with everything from rubber bands and small gas engines to beetles and flies that he glued to his aircraft.

Small, shy, physically awkward, and mildly dyslexic, MacCready tended to daydream and had to work hard to keep up in school. When it came to model aircraft, though, his focus and determination were forces to be reckoned with. At the age of fourteen, he set a world record by building a model autogyro that could remain aloft for thirteen minutes. Two years later, he was named the overall junior national champion in model building.

His interest in models led to piloting real aircraft, and at sixteen he made his first solo flight in a light plane. After graduating from Hopkins School in 1943, he enrolled at Yale. Halfway through his studies, he began training to become a Navy pilot, but World War II ended before he could fly in combat. He returned to Yale, switching majors from mechanical engineering to physics, and received a B.S. in 1947.



Bryan Allen stands in front of Paul B. MacCready's pedal-powered Gossamer Albatross in Folkstone, England, on June 12, 1979. That day, Allen successfully pedaled the plane over the English Channel, winning a £100,000 prize. (AP/Wide World Photos)

LIFE'S WORK

MacCready earned an M.S. in physics (1948) and a Ph.D. in aeronautics (1952) from the California Institute of Technology (Caltech). During his graduate studies, he continued to pilot sailplanes (a pastime he took up shortly after the war ended), winning multiple U.S. soaring championships and setting an international soaring record. His piloting experience and studies led him to develop the MacCready speed ring, an instrument used by sailplane pilots in selecting the optimum flight speed between thermal columns (now often called the MacCready speed). He also worked on sailplane development and soaring techniques. In 1956, he became the first American to win the international soaring championship.

In the early 1950's, he started a small weather modification company, Meteorology Research Inc. (MRI). The firm seeded clouds to produce rain and conducted pioneering research in atmospheric science. MacCready was the pilot on many of the company's research flights inside storm systems. In the mid-1960's, he sold MRI to Cohu Electronics, staying on as MRI's president and a member of Cohu's board until his resignation in 1970.

In 1971, MacCready founded a new company, AeroVironment, to tackle projects in solar and wind energy and in pollution monitoring and control. Although the company fared well, by the mid-1970's MacCready was facing financial difficulties. He had cosigned a bank note for a relative's business venture, which had failed. This $100,000 debt proved to be a catalyst for innovation.

In 1976, several disparate elements came together in MacCready's mind—the differing flight techniques of hawks and vultures he observed during a vacation; the amount of money he owed; the value of the British pound, then almost exactly two American dollars; and the Henry Kremer Prize, a long-standing British monetary award for the first person to fly a mile-long figure-eight course in a human-powered aircraft. The purse for the prize had recently risen to £50,000, or roughly $100,000. MacCready realized that achieving human-powered flight would be not only a way to make aviation history but also a means to erase his debt.

MacCready led a team in a yearlong effort to develop a lightweight, slow-flying, cyclist-powered craft with a large wingspan, employing flight principles he had observed in turkey vultures. His fragile creation, dubbed the Gossamer Condor, won the first Kremer Prize on August 23, 1977. Motivated by their first success (and the fact that developing the Condor had cost more than half the prize money), the team moved on to the next challenge: winning a newly established Kremer Prize for human-powered flight across the English Channel. MacCready reworked the Condor design to decrease weight and improve aerodynamic efficiency. The resulting aircraft, the Gossamer Albatross, had an increased aspect ratio (ratio of wing length to width), more ribs in its wings, and spars made from strong carbon-fiber composites instead of aluminum. The Albatross made its successful flight across the English Channel on June 12, 1979, winning a purse of £100,000 (over $200,000).

Next, MacCready and his AeroVironment team turned their attention to solar-powered flight. A scaled-down version of the Albatross was fitted with an electric motor and an adjustable solar panel. In a media demonstration held on August 7, 1980, the Gossamer Penguin flew approximately 1.95 miles at altitudes of up to 15 feet. This first sustained flight of a piloted, direct-solar-power aircraft laid the groundwork for a sturdier, more controllable solar-powered aircraft. The Penguin's successor, the Solar Challenger, could reach altitudes of up to 14,300 feet, and on July 7, 1981, it made the 163-mile trek from Paris to London in five hours, twenty-three minutes.

Perhaps the quirkiest of MacCready's winged projects was a 1984 commission from the Smithsonian Institution's National Air and Space Museum to create a flying, remote-controlled model pterodactyl. The lifelike, half-scale model (its 18-foot wingspan made it the largest known working ornithopter) appeared in *On the Wing*, an IMAX movie about the evolution of natural and manned flight. While temperamental and ungainly, the replica of *Quetzalcoatlus northropi* performed exceptionally well during filming in early 1986, although it crashed during a subsequent media event publicizing the movie's opening.

THE GOSSAMER CONDOR

The Gossamer Condor was essentially a flying wing with a gondola suspended underneath to accommodate a pilot and a horizontal stabilizer, or canard, extending in front. Construction materials were thin aluminum tubes, Mylar plastic sheeting, stainless steel wire, and countless yards of industrial-grade Scotch tape. The Condor's wingspan was 96 feet, the maximum width the hangar that was used during early testing could accommodate. At seventy pounds, the aircraft weighed less than its slender pilot, cyclist and hang-gliding enthusiast Bryan Allen. Its single, rear-mounted propeller was powered by a drive chain fashioned largely from scavenged bicycle parts. Allen, who served as the Condor's engine as well as its pilot, kept the aircraft aloft through constant pedaling.

Unlike other contenders for the first Kremer Prize, the Gossamer Condor was not built to be fast, elegant, aerodynamic, aesthetically appealing, or even safe to fly. Instead, Paul B. MacCready and his team designed an aircraft that could win the prize by taking maximum advantage of the power available to it—nothing more, nothing less. The Condor had to be able to take off under its own power, fly a 1.15-mile figure-eight course, and clear ten-foot hurdles at the beginning and end of the course. By keeping the aircraft's weight low and maximizing wingspan, MacCready minimized the power required to keep it aloft. Because it traveled so slowly (its prizewinning flight took 7 minutes, 2.7 seconds), parasitic drag from its exposed wire bracing was negligible. Its slow speed and low-altitude flight also meant that the Condor did not need to be weighed down with safety equipment. Crashes (plentiful during the many test flights) were gentle enough that the pilot could walk away from them, albeit with occasional scrapes and bruises. More likely to sustain serious damage during a crash was the aircraft itself, but its simple design and low-cost construction materials meant repairs could be made quickly, easily, and inexpensively.

The Gossamer Condor's Kremer Prize win garnered international attention and accolades and was the subject of an Academy Award-winning documentary, *The Flight of the Gossamer Condor* (1978). The aircraft is hung on permanent display in the Smithsonian National Air and Space Museum in Washington, D.C.

The Condor—bulky, fragile, and needing a serious athlete to power it for more than a few minutes—is hardly a practical invention. The Condor's value lies not in its marketability or its immediate applications. Rather, it stands as a symbol of the power of creative thinking. MacCready disregarded preconceptions about what a modern, record-breaking aircraft should be, choosing a more unorthodox approach. In so doing, he achieved a goal that had tantalized and eluded humanity for thousands of years: human-powered flight.

In the late 1980's, MacCready and AeroVironment created their first ground vehicle, the Sunraycer. A collaborative effort of AeroVironment, General Motors (GM), and Hughes Aircraft, this solar-powered car won the first World Solar Challenge Race, held in Australia in November, 1987. The Sunraycer clocked the fastest speed of all the twenty-four contestants (65 miles per hour) and remained in first place for the duration of the 1,950-mile race, coming in two days ahead of the second-place vehicle.

MacCready won multiple awards and honors during his career and was a popular lecturer on creativity, thinking skills, and environmental responsibility. He died from advanced melanoma in 2007, a month before his eighty-second birthday.

Impact

Beginning with the Gossamer Condor in 1977, MacCready's inventions captured the public imagination and attracted worldwide attention through media stories, documentaries, and museum exhibits. (The Gossamer Condor, Gossamer Albatross, Solar Challenger, *Quetzalcoatlus northropi* model, and Sunraycer are all among the Smithsonian Institution's collections.) Never intended for mass production or widespread use, these inventions instead serve as inspiring object lessons in what creative problem-solving can accomplish. Furthermore, they showcase nonpolluting, renewable energy sources and demonstrate how using lightweight materials in vehicle construction can reduce energy demands.

Much of MacCready's seemingly impractical work paved the way for practical technologies. Using lessons learned from the Gossamer Penguin and Solar Challenger (which in turn evolved from the Gossamer Condor and Albatross projects), MacCready and AeroVironment worked first with the U.S. Department of Defense and later with the National Aeronautics and Space Administration (NASA) to develop a series of remote-controlled, solar-powered flying wing prototypes. The high-altitude, long-endurance Pathfinder (1981-1997) and Pathfinder Plus (1998) were succeeded by Helios (1998-2003), which had a 247-foot wingspan and fourteen electric motors. Helios could achieve an altitude of more than 96,000 feet and had the capability to remain aloft for months at a time. Demonstration missions proved that unmanned stratospheric aircraft like these are viable, environmentally friendly platforms for scientific observation and communications relays.

Similarly, the commercially impractical Sunraycer solar car laid the groundwork for later AeroVironment-GM work on a battery-powered production vehicle. Ultimately, GM determined that its EV1 electric car (available for lease between 1997 and 2003) was not commercially viable and discontinued the project. However, the EV1 influenced air-quality standards and the development of other manufacturers' alternative-fuel vehicles.

MacCready's impact was reflected in his many awards and honors, including the Spirit of St. Louis Medal (1978), the Collier Trophy (1979), the Ingenieur of the Century Gold Medal (1980), and the Lindbergh Award (1982). He was a National Aviation Hall of Fame inductee, and in 1999 he was named by *Time* magazine as one of "the century's greatest minds."

—*Karen N. Kähler*

Further Reading

Brown, David E. *Inventing Modern America: From the Microwave to the Mouse*. Cambridge, Mass.: MIT Press, 2002. A chapter on MacCready provides an overview of his career and best-known inventions. Includes photographs of the *Quetzalcoatlus northropi* flying model pterosaur, the Sunraycer solar car, the flying wings Pathfinder and Helios, the Gossamer Penguin solar plane, and the landmark Gossamer Albatross flight across the English Channel.

Brown, Kenneth A. *Inventors at Work: Interviews with Sixteen Notable Inventors*. Redmond, Wash.: Tempus Books of Microsoft Press, 1988. An interview with MacCready explores how the Gossamer Condor came into being. MacCready also shares his thoughts on inventiveness and creativity. Includes photographs of the Gossamer Condor and Gossamer Albatross in flight, one of MacCready's early sketches of the Condor, and a later schematic of the aircraft.

Ciotti, Paul. *More with Less: Paul MacCready and the Dream of Efficient Flight*. San Francisco, Calif.: Encounter Books, 2002. Based on interviews with MacCready and his colleagues, this engaging biography yields insights into not only MacCready's personality and creative process but also the human-powered flight community. Photographs span MacCready's childhood model-building days through his later career. Extensive bibliographic notes, index.

Grosser, Morton. *Gossamer Odyssey: The Triumph of Human-Powered Flight*. St. Paul, Minn.: Zenith Press, 2004. A detailed account of the development and flights of the Gossamer Condor and Gossamer Albatross from an author-engineer who was part of the Albatross crew. Includes chapters on earlier, un-

successful attempts at human-powered flight. Numerous photographs document the development and flight of the Albatross. Schematics, bibliography, index.

See also: George Cayley; Bill Lear; Leonardo da Vinci; Stanford Ovshinsky; Andrei Nikolayevich Tupolev; Wilbur and Orville Wright.

Charles Macintosh

Scottish chemist

In 1823, Macintosh patented a waterproof fabric produced by spreading soluble rubber between two pieces of cloth. Using this fabric, he made mackintosh raincoats, an enterprise that continues today.

Born: December 29, 1766; Glasgow, Scotland
Died: July 25, 1843; Dunchattan, near Glasgow, Scotland
Primary field: Chemistry
Primary invention: Waterproof fabric

Early Life

Charles Macintosh (MAK-ihn-tosh) was born to the innovative Glasgow dye manufacturer George Macintosh and his wife, Mary Moore. Initially Macintosh worked as an accountant while he studied chemistry, first in Glasgow and later in Edinburgh under Joseph Black, a leader in practical, quantitative chemical analysis and a friend to James Watt, whose refinements to the steam engine had in 1769 inaugurated the Industrial Revolution. In 1786, at the age of nineteen, Macintosh abandoned accounting to devote his career to chemistry, chiefly in its application to the textile industry.

In his first year as a full-time chemist, Macintosh manufactured sal ammoniac (ammonium chloride) out of soot distilled from by-products of Glasgow's new coal-gas works. This compound was used to produce alum, the mordant or astringent salt that made dyes color-fast for Glasgow's expanding calico industry. Macintosh imported another mordant, sugar of lead (lead acetate), from the Netherlands, but he soon produced enough of that compound to export it to Rotterdam. He invented a chemical process for separating a third mordant, sulphate of alumina, from sulphate of lead. In 1790, he married Mary Fisher of Glasgow.

In 1792, Macintosh abandoned the sal ammoniac business, but the next year he developed a process of dyeing fancy muslin for the brand-new sewn-muslin industry in nearby Ayrshire. In 1795, Charles Tennant, a twenty-seven-year-old Ayrshire textile chemist, joined Macintosh to establish Scotland's first alum works, using the aluminous shale readily available from coal waste in abandoned mines near Glasgow. Together, they invented a bleaching powder (chloride of lime), which Tennant patented in 1799. As a weaver, Tennant had noted how inefficient it was to bleach fabric by exposing it to stale urine under sunlight for months. Bleaching powder reduced the process to mere days, dramatically reducing the price of cloth and financially rewarding its inventors.

Life's Work

In 1800, Tennant, Macintosh, and two additional partners established a chemical factory north of Glasgow, and Macintosh remained with the firm until 1814. His continued improvements to dyes included refinements of Prussian blue, a cheap substitute for indigo that produced a deep, durable shade, later called royal blue and associated with uniforms. Macintosh's interests expanded beyond textiles. In 1809, he opened a yeast factory, although opposition from London brewers soon forced him to close it. In 1825, he patented a process for making steel by using a rush of coal gas to heat iron to a white hot, a technique that led Glasgow engineer James Beaumont Neilson to develop the hot blast furnace in 1828. Though Macintosh and Neilson's invention proved essential to Scotland's iron industry, fifteen years of patent litigation deprived both men of their profits. For his many contributions to British chemistry, Macintosh was elected a Fellow of the Royal Society in 1823, the year he patented his most famous product, waterproof fabric.

By his father's death in 1807, Macintosh was running the family factory, manufacturing cudbear, a deep-red dye, from lichens soaked in ammonia water, and a decade later, he was experimenting with inexpensive ways to make Amazonian rubber soluble for practical use. Meanwhile, another Scottish-born inventor, William Murdoch, had employed coal gas for cheap artificial lighting. Piped through cities, the gas illuminated factories, theaters, and street lamps, but its production left two waste products: ammonia water and sticky, black coal tar oil. In 1819, Macintosh contracted with the Glasgow Gas

Works to buy both. The ammonia supplied his cudbear operation, and from the coal tar oil, Macintosh distilled naphtha, which made rubber soluble. He brushed the rubber adhesive onto fabric and before the naphtha evaporated, fixed a second layer of fabric over it, thus making it repel water.

To produce waterproof garments on a commercial scale, Macintosh formed Charles Macintosh and Company in partnership with three leading cotton manufacturers in Manchester, England, where the company's factory opened in 1825, powered by steam and lighted by coal gas. By supplying rainproof garments to the military as well as the public, the company succeeded despite problems with the product. Naphtha gave the fabric a disagreeable odor, and even in Britain's temperate climate, rubberized fabrics turned stiff in the cold and soft in the heat. Moreover, water penetrated the holes left by tailors' needles, and fitted rubberized garments did not allow their wearers' perspiration to escape. The man to solve these difficulties was a Londoner, Thomas Hancock.

Twenty years younger than Macintosh, Hancock had also begun in 1819 to experiment with rubber garments and in 1820 had patented elastic wristbands and garters. Around 1821, he perfected the masticator, a machine that tore and heated rubber scraps into a solid mass that could be rolled to specified thicknesses. In 1825, licensed by Macintosh to manufacture rainwear, he reduced the naphtha odor, and his brisk sales threatened Macintosh's dominance of the industry. By 1830, Macintosh had negotiated with Hancock to supply his company with rubberized fabric, and in 1834, Hancock became a partner in the company and assumed control. He replaced irregular rubber application brushes with a uniform mechanical spreader, designed loosely fitted raincoats for comfortable air circulation, and hired company tailors, supervising their stitching and replacing those who pierced cloth excessively.

In 1838, a fatal fire swept the Manchester factory while Hancock was visiting Macintosh in his Glasgow retirement. Hancock hurried south to supervise the

A WATERPROOF RAINCOAT

Charles Macintosh was the first to develop and manufacture rubberized textiles that repelled water on a commercial scale. His 1823 Glasgow invention made use of the resources of the Industrial Revolution, including textile production, coal mining, and steam shipping, as well as the growing market for his goods produced by the wealth created by industrialization.

Familiar with the growing industry of cloth manufacture from his father's business of developing dyes, Macintosh was a prosperous inventor of bleaching agents when he researched the properties of latex, still a rare and mysterious Amazonian export. Eventually he thought of dissolving it in naphtha, which he found in coal tar, a troublesome byproduct of the Glasgow Gas Works, newly built on the discovery that compressed coal gas could produce cheap artificial light. Macintosh's invention supplanted the work of Samuel Peal, who in 1791 had patented a process for coating cloth with rubber liquefied in turpentine. By substituting the more cost-effective naphtha and building a large-scale production plant in England, Macintosh's company dominated the British rubber business by mid-century, while it continued to improve the product and guard its patents.

Initially tailors resented the new fabric, which lost its special properties when their stitches pierced it or when they fashioned it into streamlined styles, so the management of Charles Macintosh and Company hired and closely supervised new tailors while redesigning a baggy garment that allowed for air circulation to combat the tendency for the wearer to perspire. The single greatest improvement to the Macintosh raincoat was vulcanization, a process of pressure-heating rubber with sulfur. Though Charles Goodyear had patented this invention in the United States in 1839, the company developed it shortly after Macintosh's death in 1843, when his partner, Thomas Hancock, secured the English patent. Named for the Roman god of the forge, vulcanization cured rubber of its propensity to soften in heat and grow brittle in cold. Airtight as well as waterproof, the improved product proved reliable not only for raincoats and boots but also for water safety, flexible surgical instruments, and industrial hoses.

Macintosh was not only an inquisitive inventor but also a skilled collaborator and a thrifty recycler. Born in Glasgow, in the second generation of the Industrial Revolution, which began in that city, he was ideally situated to market his inventions to growing local industries, particularly textile manufacturers. His successive partnerships with Charles Tennant in industrial bleaches and Hancock in rubber, as well as his financial backing from Manchester cloth producers, made most of his inventions practical and profitable. Using chemistry to discover large-scale uses for toxic industrial wastes, Macintosh both nurtured the environment and made his industry prosper. Spelled "mackintosh," his name has meant "raincoat" since 1836.

cleanup, and by 1840, an expanded Manchester operation was producing more than three thousand square yards of rubberized fabric a day. Shortly after Macintosh's death in 1843, Hancock solved the last problem with rubberized cloth when he patented the vulcanization process, which weatherproofed rubber by pressure-heating it with sulfur. Although Hancock scrupulously documented his chemical research, he concealed the source of the vulcanized rubber samples that had inspired him, the American inventor Charles Goodyear, who had held the U.S. patent since 1839.

Macintosh died in 1843 at home at Dunchattan, the estate his father had built near Glasgow for his cudbear factory. Hancock expanded Charles Macintosh and Company into the world's largest manufacturer of rubber goods while he immortalized—and altered the spelling of—the founder's name as a synonym for raingear.

IMPACT

Under Hancock's management, Macintosh and Company expanded its product line to include almost all modern uses for vulcanized rubber except inflated tires. Inflatable beds, pillows, and cushions assisted invalids and rail travelers. Surgeons used rubber tubes, sheeting, and bandages. Brewers and distillers used rubberized hose after learning how to preserve the flavors of their goods. The company supplied the military with not only waterproof capes, saddle covers, and cartridge covers but also tubes for sea divers. Pontoon boats, life preservers, hot-water bottles, and rubber boots served military and civilian needs. Inflexible rubber, called ebonite, anticipated plastic.

Charles Macintosh and Company staged award-winning displays of useful rubberized inventions at London's Great Exhibition of 1851 and the Paris Exhibition of 1855.

In 1857, Hancock noted that between 1842 and 1855, rubber imports in the United Kingdom rose from 140 tons to 2,235 tons. These exports, however, came at a cost to the native rubber workers in South America and in the new plantations of colonial Malaysia and the Congo. Modern historians estimate that in the years before World War I, the Amazon rubber industry claimed a native life for every 330 pounds of rubber it produced, while in the Congo, a native died for every 22 pounds of rubber. Public outcry and the invention of synthetic rubber have dramatically decreased the death count, even as rubber production continues to rise. In 2005, world production was 6.5 million tons of natural rubber and 8.7 million tons of synthetic rubber.

The company started by Macintosh has become Mackintosh Ltd., a Glasgow-based global company, with distributors across Europe and in North America and Japan. It markets high-end rainwear in traditional and fashionable styles to men and women using technological innovation and brand loyalty.

—*Gayle Gaskill*

FURTHER READING

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Müller, Ingo, and Peter Strehlow. *Rubber and Rubber Balloons: Paradigms of Thermodynamics*. New York: Springer-Verlag, 2004. A history of the European discovery of rubber, including how Joseph Priestley named it for its use in rubbing out pencil marks. Detailed molecular analysis of rubber's elasticity. Index, diagrams.

Schoeser, Mary. *World Textiles: A Concise History*. New York: Thames and Hudson, 2003. Describes Macintosh's invention and commercial implementations of bleaches, dyes, mordants, and rubberizing but does not identify him by name. Color illustrations, indexes, bibliography, glossary.

Slack, Charles. *Noble Obsession*. New York: Hyperion, 2002. Examines the career of Hancock. Slack feels Hancock's failure to acknowledge Charles Goodyear's contributions are a blemish on an otherwise admirable career. Illustrations, index, bibliography.

See also: Wallace Hume Carothers; Charles Goodyear; Theodor Svedberg.

THEODORE HAROLD MAIMAN

American physicist

Using a synthetic ruby rod that was silvered at both ends to reflect light, Maiman invented, demonstrated, and patented the world's first operable laser. He foresaw many of the applications of laser technology in medicine, industry, electronics, communications, and scientific research. Known as the "father of the electro-optics industry," Maiman was an inventive genius whose work led to the development and manufacture of lasers and video display systems powered by lasers.

Born: July 11, 1927; Los Angeles, California
Died: May 5, 2007; Vancouver, British Columbia, Canada
Primary fields: Optics; physics
Primary invention: Laser

EARLY LIFE

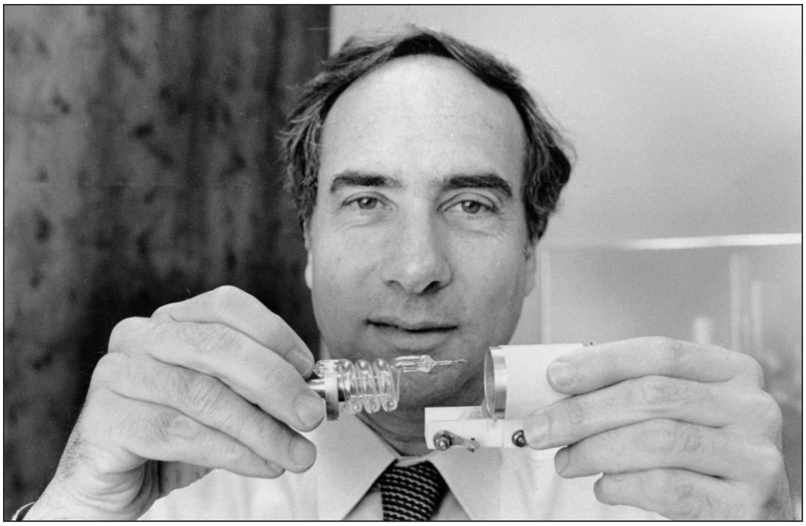
Inspired by his father, who was an electronics engineer and inventor, Theodore Harold Maiman (MAY-muhn) developed a great love for electronics and applied science at an early age. His father was very creative and was totally convinced that science should be used to better the world. He invented what was probably the first electronic stethoscope and did his best to apply electronics in the medical field and instill that same goal in his son. By the age of twelve, the younger Maiman had a job repairing mechanical valve devices. By the time he was fourteen, he ran the company's shop.

Maiman attended the University of Colorado and earned his bachelor's degree in engineering physics in 1949. After applying to do graduate work in physics at Stanford University and being rejected, Maiman attended Columbia University, but he was unhappy there. Once again, he applied to Stanford, but he was rejected a second time. Showing his tenacity, he decided to apply to the Electronics Engineering Department at Stanford and was accepted. After earning a master's degree in electrical engineering in 1951 and taking several physics electives along the way, he was finally admitted into the Stanford physics graduate program.

At Stanford, Maiman pursued his graduate research in spectroscopy under the direction of Nobel laureate Willis Lamb. His work involved making measurements of the fine-structure energy differences between particular energy levels in excited helium atoms, which were caused by the interaction of quantized electromagnetic fields with matter. Maiman built much of the electronic lab equipment necessary for making the measurements. In the process, he learned the makeup and operation of optical and electronic instrumentation that would be critical in his future work on the laser. Maiman received his doctoral degree in physics from Stanford in 1955. In a mutual agreement with Lamb prior to leaving Stanford, Maiman trained another of Lamb's graduate students, Irwin Weider, in how to use the sophisticated lab equipment to make the very precise scientific measurements that were needed to determine fine-structure energy differences in atoms.

LIFE'S WORK

During the latter part of 1955, Maiman began working at the Hughes Research Laboratories in Malibu, California. His initial work involved making improvements to the maser (microwave amplification by stimulated emission of radiation) that was invented by Charles Hard Townes in 1953. After becoming a section leader at Hughes, Maiman carefully studied a paper published by Townes



Theodore Harold Maiman holds the original laser, which he invented and patented in 1960. (AP/Wide World Photos)

LASERS

"Laser" is an acronym for "light amplification by stimulated emission of radiation." The fundamental operating principle of lasers, as demonstrated by Theodore Harold Maiman, is population inversion, a process by which energy is added to the atoms or molecules of the laser medium so that there are more atoms or molecules in a high-energy ("excited") state than in a lower-energy state. When this condition is established by optical pumping, light waves passing through the medium stimulate more radiation from the excited states than they lose by absorption to atoms or molecules in the lower-energy states.

In his laser, Maiman used a cylindrical, synthetic ruby crystal, composed of aluminum oxide doped with chromium atoms, with parallel, silver-coated ends. The crystal, or optical gain medium, was about the size of the palm of Maiman's hand. The coating on one end was semitransparent to allow emission of the amplified light. A burst of intense white light from a xenon strobe lamp acted as the optical pump to produce a population inversion in the ruby crystal and stimulate the chromium atoms in the ruby to emit incoherent red light. This red light was reflected back and forth by the silvered ends of the ruby rod until some of the light had enough energy to eventually emerge as an intense, amplified beam of coherent red light, with a wavelength of 694.3 nanometers. Because of the energy states in chromium, Maiman's laser generated pulses of laser light. The first laser to continuously emit amplified light was invented in 1961.

Lasers are used in myriad ways in household products, medicine, industry, electronics, data processing, communications, architecture, and scientific research. Lasers have been developed that can generate very high power densities, make very precise measurements of distances, gently pick up and move microscopic objects, and obtain extremely low temperatures. They are invaluable medical and scientific instruments that have developed into a multibillion-dollar industry. The United States National Academy of Engineering selected the use of lasers and fiber optics in communications as one of the twenty most important engineering developments of the twentieth century. In general, laser design still follows the guiding principles established by Maiman.

and Arthur L. Schawlow in 1958 that discussed the theoretical possibility of constructing an optical maser, or laser, that amplified visible light. Beginning in 1959, a race ensued to see who would be the first to invent a working laser. Several prominent physicists, including Townes, Schawlow, and Gordon Gould, submitted designs and sought patents for a light amplifier, but a working device was still not available. At least nine very important labs were pursuing the goal, including General Electric, Westinghouse, Siemens, and Bell Laboratories.

At Hughes, Maiman pursued the invention of an operable light amplifier on a shoestring budget. His initial pursuits involved investigating ruby as a lasing material, since it had been used successfully in making masers. Other scientists ridiculed him for his choice, particularly after Weider, whom Maiman had trained at Stanford, reported that the fluorescence quantum efficiency of ruby was a dismal 1 percent. After investigating other materials and finding no alternative prospects, Maiman recalculated the efficiency of ruby and found it to be about 75 percent. He then returned to experimenting with ruby.

Since other laboratories were trying to invent a continuous-emitting laser instead of a pulsed laser, Maiman pursued the possibilities of inventing a continuous-emitting ruby laser, using for optical gain a continuous arc lamp that had a brightness temperature of about 4,000 kelvins. He found that his margin of safety for success was too minimal to take the risk on his small operating budget. Surveying the literature, he located an article on photographic strobe lamps that could generate brightness temperatures between 8,000 and 9,000 kelvins. After numerous calculations, Maiman decided that the strobe lamp could provide the optical gain necessary to make a ruby rod emit amplified pulses of light.

In late 1959, Maiman requested Union Carbide to manufacture for him an optically finished ruby rod. Using techniques learned earlier during his graduate work and lab research, he silvered both ends of the rod so that light would be reflected inside the rod. One end was half-silvered so that light could escape through it when it reached a large enough amplitude. Maiman surrounded the rod with a high-power, helical-shaped xenon strobe lamp. On May 16, 1960, he tested his invention at Hughes Research Laboratories. As he had predicted, energy released from the strobe lamp excited atoms in the ruby rod to higher energy states, initiating a release of energy inside the rod. The resulting internal chain reaction caused light to bounce back and forth within the ruby. Once the light reached a certain level of amplification, it escaped from the partially silvered end of the ruby rod in the form of intense pulses of coherent, monochromatic light. Maiman had succeeded in inventing the first working laser in the world.

A public announcement about the working laser was reported to the news media by Hughes Research Laboratories on July 7, 1960. In the meantime, Maiman submitted a short paper describing his invention and results to *Physical Review Letters* for publication. To his dismay, the paper was rejected. Eager to have this significant work published, he submitted it to *Nature*, where it was published on August 6, 1960. The rejection by *Physical Review Letters* indicates the limited understanding at the time of the nature and significance of lasers.

Realizing the important applications for lasers, Maiman joined Quantatron in late 1960 and supervised laser research there. In 1962, he formed his own company, Korad Corporation, for the research and production of lasers. After Korad was purchased by Union Carbide in 1968, Maiman established Maiman and Associates, a company devoted to the development and manufacture of lasers and other optical devices. Four years later, he cofounded Laser Video to develop large-screen, laser-driven video display systems. In 1976, he became the vice president for advanced technology of TRW Electronics. He also served as a director of Control Laser Corporation and a member of the advisory board of *Industrial Research Magazine*. Maiman died on May 5, 2007, at the age of seventy-nine.

IMPACT

During the latter part of his Ph.D. studies, Maiman established a goal that he would be the first in the world to invent a working laser. When he began to pursue this goal, he was a junior employee at Hughes Research Laboratories with little experience. Although he was ridiculed by some of the world's leading scientists for not following their recommendations about how to build a laser, he stuck with his intuition and inventive genius. He believed that too often scientists follow the dictate of the scientific establishment and wind up wasting precious time and effort. Part of his inventive philosophy was to adhere to the principle of Occam's razor: Keep things as simple as possible. By doing so, he felt that he would avoid many pitfalls and blind alleys in his pursuits. He had confidence in his scientific decisions because he had put in the necessary time and hard work to develop a solid foundation in the understanding of electronics and optics, the keys for a working laser.

As Maiman forged ahead with his laser research, Hughes management grew skeptical about whether he would ever succeed. In addition, intense rivalries existed among individuals and scientific laboratories in the race to build the first working laser. By the time that Maiman became the first to succeed, Hughes management had already told him to quit working on the project. Nevertheless, Maiman endured until he succeeded in achieving his goal. His tenacity and competitive spirit earned him the label of being a maverick scientist. In addition to inventing the first working laser, Maiman applied his inventive philosophy to obtain patents for his inventions associated with masers, laser displays, optical scanning instruments, and laser modulation devices.

The significance of Maiman's inventive genius and scientific contributions is manifest by the numerous prestigious awards he received. He was presented the Ballantine Medal of the Franklin Institute (1962), the Buckley Solid State Physics Prize of the American Physical Society (1966), the Fanny and John Hertz Foundation Award for Applied Physical Science (1966), the Wood Prize of the American Optical Society (1976), the Wolf Prize in Physics from Israel's Wolf Foundation (1984), the SPIE (International Society for Optical Engineering) President's Award (1985), and the Japan Prize (1987), the Asian equivalent of the Nobel Prize. He was twice nominated for a Nobel Prize in Physics.

—*Alvin K. Benson*

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Garwin, Laura, and Tim Lincoln, eds. *A Century of Nature: Twenty-one Discoveries That Changed Science and the World*. Chicago: University of Chicago Press, 2003. Contains a discussion of Maiman's work, insights, and struggles in developing the world's first working laser. Describes many of the laser applications in science, technology, and medicine that have affected the world.

Hecht, Jeff. *Beam: The Race to Make the Laser*. New York: Oxford University Press, 2005. Hecht provides the history associated with Maiman's invention of a working laser, the culmination of years of theoretical and applied research. He describes the race to get there, the people, the labs, the approaches, the debates, and the battle for recognition. A number of period photographs are included, as well as an index and comprehensive bibliographical references.

Wyckoff, Edwin Brit. *Laser Man: Theodore H. Maiman and His Brilliant Invention*. Berkeley Heights, N.J.: Enslow, 2007. Written as a tribute to Maiman and his inventive genius in the development of the first operable laser. Gives a clear explanation of laser operation that is suitable for younger readers starting at the fourth-grade level.

See also: Willard S. Boyle; Gordon Gould; Ali Javan; Arthur L. Schawlow; Charles Hard Townes.

LEOPOLD MANNES

American photographic technician and musician

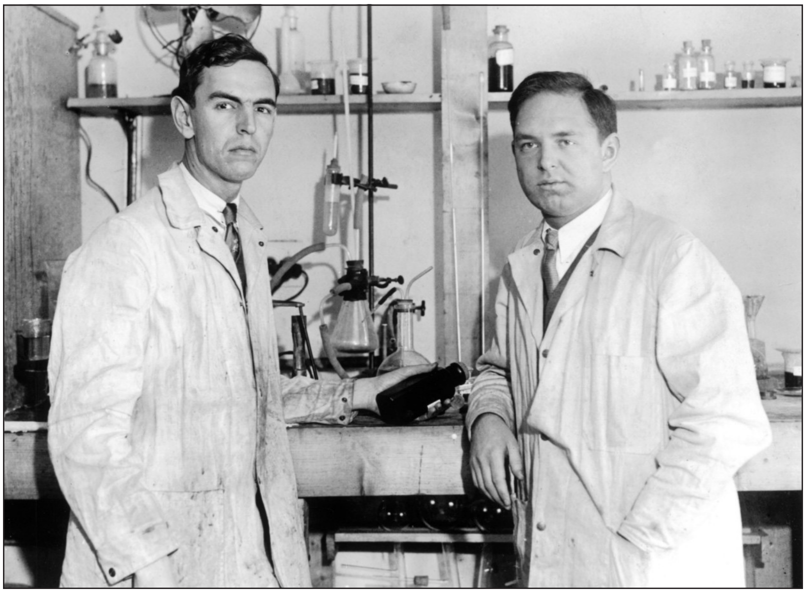
Mannes's boyhood curiosity and infatuation with color photography eventually resulted in an innovative form of superb color film reproduction. Kodachrome was mass-produced and used by amateur and professional photographers for generations.

Born: December 26, 1899; New York, New York
Died: August 11, 1964; Vineyard Haven, Massachussetts
Also known as: Leopold Damrosch Mannes (full name)
Primary field: Photography
Primary invention: Kodachrome color film

EARLY LIFE

The Damrosch family settled in New York and successfully launched careers in music as German immigrants. Leopold Damrosch conducted a men's choral ensemble, the Arion Society, and established the Oratorio Society of New York and the Symphony Society of New York. Clara Damrosch, the daughter of Leopold and an accomplished pianist, married David Mannes, violinist and concertmaster of the New York Symphony Orchestra, in 1898. Their son, Leopold Damrosch Mannes (MAN-ihs) was born the following year. At age four, studying piano with Elizabeth Quaile, he was already being compared to Mozart because of his considerable musical talent. At New York City's Riverdale School, Mannes met Leopold Godowsky, Jr., and formed a friendship that eventually led to their collaboration as musicians and inventors.

During his teens, Mannes devoted less time to music and developed a keen interest in photography. In 1917, he and Godowsky, also a highly trained classical musician, watched a movie, *Our Navy*, which was advertised as a color motion picture. Both expressed disappointment with the quality of reproduced color and decided they could improve upon current techniques. The boys constructed a movie camera and projector of their own that utilized three lenses with red, blue, and yellow filters. By projecting black-and-white exposures through the filters, the color hues were greatly enhanced. The system was patented but had little influence on the industry.



Leopold Godowsky, Jr., and Leopold Mannes, nicknamed "God and Man" by their friends, at the laboratory in Rochester, New York, in 1935, the year they invented Kodachrome. (Getty Images)

LIFE'S WORK

The two Leopolds went their separate ways. Godowsky studied violin at the University of California, Los Angeles, and became first violinist of the Los Angeles and San Francisco Symphony Orchestras. Mannes graduated from Harvard University

KODACHROME

Colors in a photograph are not actual recorded colors but instead are re-creations. The popularity and success of Kodachrome, the first transparency material, was due to its clear and fine-grain images that retained vivid colors over time. The process developed by Leopold Mannes and introduced to the public in 1935 was the first "tripack" process. Three emulsions with included filters were layered on a piece of film. Most other films required dye couplers embedded in the film, and all three layers were developed simultaneously. With Kodachrome, there were no dyes already embedded in the film. Kodachrome film used three layers of black-and-white film that were sensitive to red, green, or blue light. The dyes were added in the processing, separately for each color, through two specific light reexposures and another step that required chemical fogging. Each emulsion layer was exposed to a colored light and then developed. More dye was transferable to the film because the dye was added separately during each of the three color developments. The result was that colors were more saturated and of finer grain. Importantly, the process stabilized over time and the colors were fade-resistant. Kodachrome slides more than fifty years old maintain precise color and grain. It is estimated that the unstable yellow will lose only 20 percent of its color and grain in 180 years.

The reproduction of color is accomplished by mixing red, green, and blue light in the correct balance, each sensitive to one of the emulsion layers. The layers are so thin, including the gelatin layer between each, that the overall thickness of the film is less than most black-and-white films. Three color records of the film are assembled with blue sensitive (with yellow and yellow filter) at the top, blue-green sensitive (magenta) in the middle, and blue-red sensitive (cyan) on the bottom. The gelatin layer keeps each color record clearly separated. Dye images in each layer regulate the transmission of blue, green, and red light through the negative. For superior color, each dye image must be limited to only one primary color—red to cyan, for example. The red image is capable of transmitting green and blue as well, but those colors disappear when viewed through green and blue filters. The end result is three color records, each paired with the selective dye. Over time, formulas changed but the selective reexposure process remained basically the same.

Kodachrome film and the development process were invented by Mannes and his friend Leopold Godowsky, Jr., two classical musicians with a penchant for color photography. Their discovery expanded the possibilities and capabilities for amateur and professional photographers for decades. As with all improvements in technology, there is a finite time span for usage. However, countless magazine pictures, family vacations, artistic photo shoots, and memoirs are permanently preserved as testaments to the merit and excellence of Kodachrome.

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in 1920, then went to Paris to study piano with Alfred Cortot and also won a Pulitzer scholarship in composition in 1925. In 1926, Mannes married Edith Vernon Simonds and received a Guggenheim Fellowship to study composition in Rome for eighteen months. Mannes and Godowsky regularly communicated regarding their plans to improve color photography. Godowsky eventually left his symphony positions to join Mannes in New York, where they both continued their musical careers. The kitchens and bathrooms in their homes served as darkrooms for their photography experiments.

By chance in 1922, Mannes encountered a senior member of Kuhn, Loeb and Co., a prominent investment banking firm. Mannes mentioned their work in color photography, and the firm sent an associate to review the progress. The firm expressed confidence in the developing process and provided $20,000 in financial support to build a photography laboratory in 1924. By 1930, the results of their work were so impressive that the inventors were invited to join the staff of Eastman Kodak in Rochester and were assigned a group of researchers to assist.

Days were spent in the laboratory, while evenings provided opportunities for musical performances at the nearby Eastman School of Music. Since their work in the laboratory required total darkness and they were unable to look at a watch to time film developing, they concocted their own system by singing or whistling classical music compositions such as the final movement of Brahms's C-minor Symphony at two beats per second. This formula was used to determine specific time intervals.

Godowsky and Mannes were affectionately labeled by friends and colleagues with the nicknames "God and Man." God and Man successfully completed their work on a new type of color film within three years of their research. On April 5, 1935, the two inventors announced the arrival of Kodachrome, a revolutionary but practical color photography film that provided excellent results and was also easy to use. At the press conference, there was an announcement of the new product accompanied by sample photographs, and, as usual, unable to separate their music and science careers, the duo performed a violin and piano sonata. In subsequent years, Ektachrome, Ektacolor, and Kodacolor were developed, but Mannes and Godowsky were not participants.

Oddly, after almost twenty years of discussion, testing, and research on improving color photography, Godowsky and Mannes abruptly halted their work in photography. Both decided to resume their music careers. Mannes and Edith had divorced in 1933, and he returned to New York City after 1939 to perform, compose new works, and serve as an adjudicator for music competitions. He judged the first Van Cliburn International Piano Competition. In 1940, he assumed the position of assistant director of the prestigious Mannes School of Music, founded by his father, David Mannes, in 1916. He also served on the faculty, teaching theory and composition. That same year, he married Evelyn Sabin, a dance student of the renowned Martha Graham.

In 1948, Mannes was codirector of the Mannes School and became president in 1950. He continued to perform with the Mannes Trio (piano, violin, and cello), which he had established in 1948. The year 1953 was noteworthy. Under Mannes's leadership, the name of the school changed to the Mannes College of Music, and new degrees were offered. The highly regarded Techniques of Music program was also created.

Leopold Mannes remained as president of the Mannes College of Music until he died at age at age sixty-four at Vineyard Haven in Massachusetts. In 2005, Godowsky and Mannes were inducted into the National Inventors Hall of Fame.

IMPACT

Critically acclaimed as a concert pianist, university music professor, and administrator, Mannes also invented a product that revolutionized an industry. His lifetime achievements uniquely combined art and science. After a long and prosperous performing career had peaked, Mannes introduced new curriculum tracks at the prestigious Mannes College of Music in his role as director. The new programs continued to evolve and now serve the college students of today. After many years of study and research that essentially began as a hobby, he developed Kodachrome, which became the industry standard for color photography worldwide.

For decades, Kodachrome was the overwhelming choice of photographers due to its characteristic bright colors, striking contrasts, and resistance to fading. It was especially suitable for printing in popular magazines such as *National Geographic* and *Look*. Historic images such as the fiery explosion of the *Hindenburg* zeppelin in 1937 and Sir Edmund Hillary's photo of his climbing partner atop Mount Everest in 1953 are preserved and still revered thanks to Kodachrome.

Remarkably, Mannes's successes in both music and photography were paralleled by those of a childhood friend, Leopold Godowsky, Jr., who accompanied him on his journey and made significant contributions as well. Together, the musical partners dabbled in the science of film and color and helped establish Eastman Kodak as the largest photographic film distributor in the world.

Gradually, the stockpiles of Kodachrome are diminishing as technology inevitably advances. Kodachrome is now available only in 35mm form, 64 ISO speed. In the United States, only one laboratory in Kansas continues to process the film. Even the finest and most trusted products often have a short shelf life. The digital age is taking its toll.

—Douglas D. Skinner

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Nicholas, Jeremy. *Godowsky: The Pianists' Pianist*. Hexham, Northumberland, England: Appian Publications and Recordings, 1989. Primarily a musical biography of Leopold Godowsky, friend and coinventor of Kodachrome with Mannes. Their combined efforts led to improvements in color photography through the invention of Kodachrome.

Rijper, Els. *Kodachrome: The American Invention of Our World, 1939-1959*. New York: Delano Greenidge Editions, 2002. More than two hundred photos, originally taken with black-and-white film, are displayed with Kodachrome colorization. The book contains perspectives of American cities, personalities, sports, fashion, politics, and culture of the mid-twentieth century.

Stricherz, Guy. *Americans in Kodachrome 1945-1965*. Santa Fe, N.Mex.: Twin Palms Press, 2002. A family scrapbook collection of ninety-five color photographs from more than ninety different photographers depicting scenes of American daily life during a twenty-year period.

See also: Louis Jacques Daguerre; George Eastman; Leopold Godowsky, Jr.

GUGLIELMO MARCONI

Italian physicist

Marconi introduced improvements in sending and receiving wireless telegraph signals, and he developed the first commercial radiotelegraph system. He was also the first to demonstrate long-distance wireless transmission across the Atlantic Ocean.

Born: April 25, 1874; Bologna, Italy
Died: July 20, 1937; Rome, Italy
Primary field: Communications
Primary invention: Wireless telegraph system

EARLY LIFE

Guglielmo Marconi (gewl-YEHL-moh mahr-KOH-nee) was born at his father's villa, Palazzo Marescalchi, near Bologna in northern Italy. He was the second son of Giuseppe Marconi, an Italian landowner, and his Irish wife, Annie Jameson, daughter of Andrew Jameson of Daphne Castle in County Wexford, Ireland, and granddaughter of the founder of the Jameson Whiskey distillery. Guglielmo often visited relatives in Great Britain with his mother and learned to speak English as a child, but he did poorly in school because of frequent travels.

Marconi received private education at Bologna, Livorno, and Florence, and took an interest in physical and electrical sciences. After the death of Heinrich Hertz in 1894, Marconi read reports of his discovery of radio waves and about Nikola Tesla's work with radio waves. Through family connections, he was allowed to study for a period of time in Augusto Righi's physics laboratory at the University of Bologna. This began a long relationship with Righi, who had studied the works of Hertz and had developed an improved oscillator and spark gap for generating radio waves.

In 1895, Marconi began his own experiments with radio waves in the attic of his father's country home, Villa Griffone, at Pontecchio, Italy. After assembling his own spark-gap transmitter and using a receiver with a metal-filing coherer in place of a spark gap, as developed by Edouard Branly, he succeeded in transmitting across the length of the attic. After several improvements, he took his equipment outdoors in the summer of 1895 and began to reach greater distances by using longer antennae oriented vertically and grounded at one end. Soon he was able to transmit signals to associates, who received them at distances of a kilometer and a half and even out of sight over a hill, leading him to consider commercial possibilities for a wireless telegraph system.

LIFE'S WORK

Early in 1896, Marconi traveled to London with his mother, taking his equipment with him to seek support for developing his idea. Through his cousin, Henry Jameson-Davis, he met William Preece, engineer in chief of the British Post Office, who agreed to observe a test of his equipment and to provide some technical support. Later in 1896, after several demonstrations in London, Marconi was granted the first patent for a wireless telegraph system, even though very little of his equipment was his original invention. His work was introduced to the public in December, 1896, by Preece in a London lecture on "Telegraphy Without Wires," which included a public demonstration by Marconi. This was followed six months later by a second lecture by Preece at the Royal Institution in London on "Signalling Through Space Without Wires."

Marconi continued his demonstrations for the British government, and in March of 1897, he transmitted Morse code signals and received them on a paper tape recorder at a distance of about 6 kilometers across the Salisbury Plain southwest of London. On May 13, 1897, he sent the first wireless signals over water, transmitting the message "So be it, let it be so," across the Bristol Channel in South Wales for a distance of 6 kilometers from Lavernock Point to Flat Holm Island. He then relocated his receiving equipment to Brean Down Fort on the Somerset Coast, extending his transmission range to 16 kilometers.

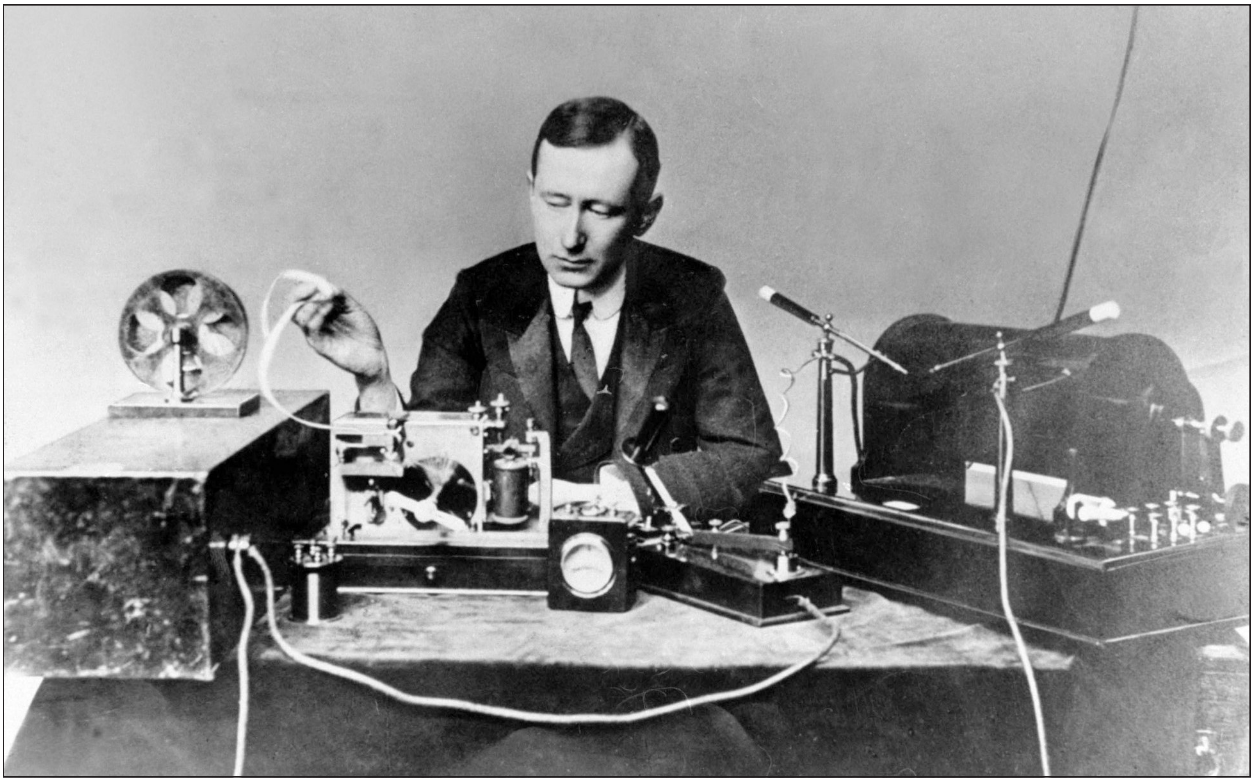
Bypassing the British Post Office, Marconi formed the Wireless Telegraph and Signal Company in July of

1897, with generous financial backing from a syndicate formed by Henry Jameson-Davis. In the same month, he received a U.S. patent and carried out a series of tests for the Italian government at La Spezia, where wireless signals were sent over a distance of about 20 kilometers. By the end of 1897, when he was only twenty-three years old, Marconi's stock holdings in his new company had tripled in value and were worth the equivalent of about $20 million.

In 1898, Marconi opened a radio factory at Chelmsford, England, to produce the equipment needed for permanent wireless stations. A test for Lloyds of London was conducted in July of 1898 between Ballycastle and Rathlin Island, Ireland, leading eventually to a contract to build ten wireless stations for Lloyds. About the same time, Marconi responded to a request from Queen Victoria to provide a wireless service from her royal yacht to her estate at Osborne House in Wales. In March of 1899, he established wireless stations at Wimereux, France, and South Foreland Lighthouse, England, and transmitted the first signals across the English Channel over a distance of some 50 kilometers. In the fall of 1899, the *New York Herald* invited Marconi for his first wireless demonstrations in the United States, reporting the America's Cup yacht races from a station on board the SS *Ponce* that transmitted the results to the mainland.

By the end of the century, Marconi faced increasing competition from other wireless inventors, especially Oliver Lodge, Nevil Maskelyne, and Nikola Tesla. To keep ahead of his competition, he began planning ways to transmit signals across the Atlantic, even though accepted scientific opinion held that radio waves could not bend around the curvature of Earth. With the assistance of John Ambrose Fleming as his scientific adviser, he established a high-power transmitting station on the cliffs near the village of Poldhu in Cornwall, England.

Marconi and his associates then traveled to St. John's, Newfoundland, a British territory at that time, and set up a receiving station on Signal Hill. Using a 150-meter kite-supported antenna, he began to hear prearranged signals from Poldhu, which were too weak to record on tape. On December 12, 1901, he announced his success in receiving signals over some 3,500 kilometers of open water. Although this was hailed as a great achievement,



Guglielmo Marconi with devices similar to those he used to transmit the first transatlantic wireless signals. (Time & Life Pictures/ Getty Images) critics voiced skepticism because there was no physical evidence or independent verification.

To verify and document his claims, Marconi sailed from England on the SS *Philadelphia* in February of 1902 and received tape-recorded signals from the Poldhu station out to 2,500 kilometers, although he could receive signals out to only 1,125 kilometers during the daytime. This daylight effect, limiting the transmission of long radio waves during the day, was explained by Oliver Heaviside's proposed existence of the ionosphere. He suggested that charged particles in the upper atmosphere reflect radio waves around the curvature of Earth, and that they reflect better at night when the Sun does not affect the ionosphere.

Due to threatened legal action by British transatlantic cable interests, Marconi built a new station at Glace Bay, Nova Scotia, Canada. On December 17, 1902, he transmitted the first transatlantic wireless signals from North America. His first transmission from the United States was a message from President Theodore Roosevelt to King Edward VII on January 18, 1903, from his Wellfleet station on Cape Cod in Massachusetts. A regular, but not completely reliable, transatlantic wireless telegraph service began in October of 1907 between Clifden, Ireland, and Glace Bay. Although Marconi was slow to accept continuous-wave radio for audio transmissions, made possible by Fleming's invention of the vacuum tube in 1902, he finally used a vacuum-tube transmitter in 1920 at his Chelmsford factory to transmit the first voice broadcasts in the United Kingdom.

IMPACT

Marconi's main contributions were in showing the feasibility of using radio waves for communication, establishing the first commercial wireless telegraph systems, and demonstrating the first transatlantic wireless transmissions of telegraph signals. His tireless efforts to improve radio transmission and reception led to steady increases in the distance that signals could be sent. His persistence and promotion made it possible to raise the funds for building wireless telegraph stations in several countries and on board many ships. He was able to establish several wireless companies, including a factory for producing radio equipment, and provided the basis for worldwide wireless telegraphy. The use of shipboard telegraphy became crucial in seafaring emergencies, as in the 1912 sinking of the *Titanic* when many lives were saved because of Marconi's radio operators.

Although few of Marconi's inventions were original, his most dramatic achievement was in transmitting wireless signals across the entire Atlantic Ocean, against all scientific opinion of the day. In the process, his success led to the eventual discovery of the ionosphere and of the daylight effect that reduces the ability to reflect long radio waves during daytime. Marconi shared the 1909 Nobel Prize in physics with German physicist Karl Ferdinand Braun, who invented the crystal-diode rectifier for more efficient detection of radio waves, "in recognition of their contributions to the development of wireless telegraphy."

—Joseph L. Spradley

THE WIRELESS TELEGRAPH SYSTEM

Guglielmo Marconi developed and commercialized his wireless telegraph system from known principles, and his innovations were mostly improvements by trial-and-error experiments based on the inventions of others. His system included a transmitter consisting of a simple oscillator with a pulsed power source and an induction coil connected to a wire antenna extending from each side of a spark gap, similar to that used by Heinrich Hertz. He also used a receiver with an antenna and coil, but Hertz's receiving spark gap was replaced by a coherer consisting of metal filings in a glass tube that would conduct current when a signal was received, similar to Edouard Branly's original coherer but modified for improved sensitivity. Messages were sent with a telegraph key to actuate shorter and longer sparks in the transmitter corresponding to the dots and dashes of Morse code. They were received with a telegraph register to record signals on a roll of paper tape when actuated by the coherer.

Marconi used a two-stage circuit to achieve the higher power he needed for long-distance transmission. He connected the first stage to a lower voltage generator, and the second stage operated at a higher voltage for more powerful sparks. Concerns about the extreme power of his Poldhu station led Marconi to investigate methods of tuning the frequency of his transmitter to avoid interference with other stations by adding sheets of metal to the top and bottom of his antenna, based on earlier ideas by Oliver Lodge. This led to a more effective four-circuit design, with two tuned circuits in both the transmitter and receiver, for which he received his famous British patent number 7,777 for "tuned or syntonic telegraphy" in 1900. Six years after Marconi died, the U.S. Supreme Court overturned most of his U.S. patents, based on prior work done by Nikola Tesla, Lodge, and others.

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See also: Ernst Alexanderson; Edwin H. Armstrong; Karl Ferdinand Braun; Martin Cooper; Lee De Forest; Thomas Alva Edison; Reginald Aubrey Fessenden; Oliver Heaviside; Heinrich Hertz; David Edward Hughes; Nikola Tesla.

JAN ERNST MATZELIGER

American machinist

Matzeliger's shoe-lasting machine made such a change in the shoemaking industry that shoe production in the United States in particular increased tremendously. Manufacturing costs were cut in half, and the product was made affordable.

Born: September 15, 1852; Paramaribo, Dutch Guiana (now in Suriname)
Died: August 24, 1889; Lynn, Massachusetts
Primary fields: Industrial technology; manufacturing
Primary invention: Shoe-lasting machine

EARLY LIFE

In 1852, the year in which Harriet Beecher Stowe published her scathing exposé of American slavery, *Uncle Tom's Cabin*, in book form, Jan Ernst Matzeliger was born in Dutch Guiana, on the northern coast of South America. He took his name from his father, a Dutch sea captain who was also an engineer. His mother was a black slave. By the time he reached the age of ten, the young Jan was working in machine shops that his father supervised. A smart child with an obvious mechanical aptitude, he was encouraged to develop his mechanical talents and his interest in machinery. At the age of nineteen, he left South America aboard an East Indian merchant ship and spent two years at sea. When his ship made port in Philadelphia, Pennsylvania, he decided to settle in the United States.

Matzeliger arrived in the United States during the early 1870's, a time when the nation was recovering from its devastating Civil War (1861-1865) and its craftsmen were adjusting to changes wrought by the Industrial Revolution. Few jobs were open to black men, much less to a black foreigner who could barely speak English. Having trouble finding gainful employment, Matzeliger took odd jobs to survive while he learned to speak better English. On one job, he was an apprentice shoemaker. Aware of the bustling shoemaking industry in New England, he soon moved to Boston and then to Lynn, Massachusetts, where he found employment at the Harney Brothers shoe factory. There, he learned to use a sole-sewing machine, a heel burnisher, and a buttonhole machine.

Matzeliger had a high regard for learning. When he was not working, he studied English, physics, and other subjects. In addition to his interest in things mechanical, he also had a talent for painting. He gave his paintings to acquaintances and associates and even taught oil-painting classes. However, he seems to have had difficulty making friends and developing a social life, and there is no evidence that he ever courted or married a woman. A religious man, he tried several times to join a church in Lynn but was always refused membership because he was black. Eventually, however, he was allowed to join Lynn's North Congregational Church; he became a devoted member, regularly attending services and even teaching Sunday school.

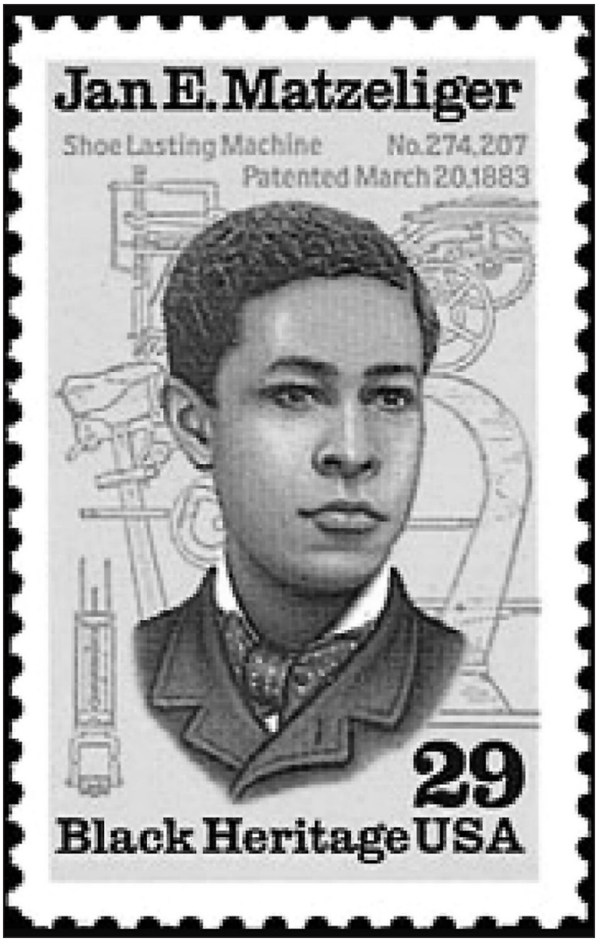
LIFE'S WORK

Meanwhile, Matzeliger's job in the shoe factory made him acutely aware of shortcomings in the shoe manufacturing process. Thanks to the Industrial Revolution, new machines had been devised to cut, sew, and tack shoes. The invention of the sewing machine had ushered in marvelously fast methods of attaching the various upper shoe parts together, but attaching the upper parts to the shoes' soles still had to be done by hand—a slow and expensive process. Shoe lasters, the skilled workers who performed this task, had a strong labor union and could dictate how many shoes they would finish each day and how much they should be paid for their work. Shoe workers who operated the machines could produce upper parts much faster than hand lasters could finish the shoes, but the number of shoes finished in a given day was generally no more than the fifty each laster could sew by hand. Many inventors had tried and failed to mechanize the lasting process, but Matzeliger believed that he could invent a shoe-lasting machine that would do the job faster and more efficiently than human hands could.

Alone and with little financial support from outside sources, Matzeliger worked on the lasting problem. Those who knew what he was trying to do were quick to scoff at him. Nevertheless, he kept at it until he assembled a model of his machine with old cigar boxes and scrap wood that was held together with wire and nails. Though his model was fragile, it clearly demonstrated the feasibility of his invention. After turning down another inventor's offer of $50 for the model, Matzeliger set out to make a metal model of his machine that could be put to a practical test. Knowing how expensive building such a model would be, he switched jobs so that he could have access to a forge at his workplace. Using scrap metal, he finally made a working model of his machine after several years of effort.

After turning down another inventor's offer of $1,500 for his new model, Matzeliger sought investors to put up money for a metal model strong enough for strenuous factory testing. Two men, C. H. Delnow and M. S. Nichols, gave him the money he needed, in exchange for two-thirds of his invention's profits. Matzeliger then joined with them to form the Union Lasting Machine Company and applied for a patent for his machine. His application was several pages long and contained such complicated drawings and descriptions of the machine that the U.S. Patent Office sent an examiner to Lynn to see his machine in action. When Matzeliger demonstrated how the machine held the last, pulled the leather upper shoe parts over it, and nailed the parts together, he was granted a patent.

Matzeliger's machine lived up to its promise, and Matzeliger continually made improvements that eventually enabled each machine to finish from 150 to 700 pairs of shoes per day. Every shoe manufacturer in the country wanted one of his machines. Within two years of the machine's availability, hand-finishing methods had been replaced by the machine that duplicated the movements of the human hand in shoe making.



A U.S. postage stamp issued in 1991 honors inventor Jan Ernst Matzeliger. (© United States Postal Service)

THE SHOE-LASTING MACHINE

Jan Ernst Matzeliger's hand-lasting machine automated the final step in the shoemaking process, which had long defied all attempts at mechanization. By the 1870's, all the upper parts of shoes—heels, toes, vamps, tongues, counters, and linings—could be assembled and sewed together by machines. Steam-powered sewing machines stitched together all upper parts, but no machine existed that could join those parts with the shoe's soles.

Before he began designing his invention, Matzeliger spent months observing exactly how lasters hand-sewed soles to shoes. After much experimentation, he devised a machine that duplicated their hand motions. His machine held the already-sewn upper parts of a shoe to a last—the foot-shaped wooden form used to shape each shoe to fit a different-sized human foot. As his machine gripped the leather upper, it also pulled it down around the heel and toe and drove nails into the sole, thereby joining the upper and bottom parts. The machine performed the entire process, fitting to the last and stitching the sole while adjusting its edges under the insole, in about one minute. Lasts were shaped approximately like human feet, but early models did not differentiate between left and right feet, so every shoe could be worn on either foot.

Before Matzeliger's invention revolutionized shoe production, most average people could not afford to buy the shoes made mostly by hand. Even shoes made partly by machine but finished by hand-lasters were too expensive for ordinary people. Matzeliger's machine lowered production costs so much that practically every American could buy manufactured shoes, and eventually the cost of shoe production fell all over the world.

Matzeliger continued working on projects to improve his lasting machine and other aspects of the shoemaking process. In 1890, he patented a nailing machine and a mechanism for separating and distributing tacks. In 1891, he patented another lasting machine and in 1899 another tack-and-nail distributing mechanism.

During the years that Matzeliger devoted to his inventions, he led a lonely life. However, his involvement with the Christian Endeavor Society at the North Congregational Church afforded him the solace of his strong Christian faith. He also made friends in the church who joined him in recreational activities, including rock climbing and exploring nearby ponds and islands. After an outdoor excursion in 1886, he came down with what he thought was a cold but what in fact was the onset of tuberculosis. Years of not eating properly and getting insufficient rest while concentrating on his inventions allowed the disease to take hold and eventually confine him to bed. For a while, he continued to work on his projects and paint. However, on August 24, 1889—several weeks before his thirty-seventh birthday—he died. He was buried in Pine Grove Cemetery in Lynn, Massachusetts.

After immigrating to the United States, Matzeliger had had little contact with his family in Dutch Guiana, so he left much of his estate to his Lynn, Massachusetts, church. When the church fell on hard financial times many years later, stock in his company that Matzeliger had left it rescued it.

IMPACT

Matzeliger's shoe-lasting machine was one of the greatest small inventions of the Industrial Revolution. It enabled manufacturers greatly to increase their production of shoes while cutting production costs in half, and its impact was almost immediate. It freed manufacturers from the tyranny of the hand-lasters who had formerly demanded—and received—high wages that had stifled the industry. With increased production and lower costs, retail prices of shoes fell to levels at which many people who had never before worn commercially produced shoes could afford them.

At the same time, conditions for workers in the shoe industry improved. Inequalities between the wages of high-paid hand-lasters and machine workers were balanced with increased pay for machine workers and modifications for hand-lasters. Hand-lasters became hand-lasting machine workers and produced ever more shoes. Meanwhile, Lynn, Massachusetts, became known as the "shoe capital of the world."

Over the years, the company Matzeliger and his backers had founded merged with other companies to become the United Shoe Machinery Corporation. By 1955, it was worth more than a billion dollars. Even into the twenty-first century, virtually all shoes manufactured by machines were still using machines based on Matzeliger's model. The fact that people all over the world have been able to wear machine-made shoes thanks to the genius of an obscure man from Dutch Guiana was little known for many years. However, long after his death, recognition and honors finally came his way. In 1967, his North Congregational Church had a statue of him erected in downtown Lynn. In 1984, the city of Lynn named one of its bridges after him. Seven years later, the U.S. Postal Service issued a commemorative stamp honoring him.

—Jane L. Ball

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See also: Caresse Crosby; Elias Howe; Isaac Merrit Singer.

JOHN WILLIAM MAUCHLY

American physicist and engineer

Mauchly, together with John Presper Eckert, designed and built the first general-purpose electronic digital computer, the ENIAC. They later established the Eckert-Mauchly Computer Corporation and built the first commercial computers made in the United States.

Born: August 30, 1907; Cincinnati, Ohio
Died: January 8, 1980; Ambler, Pennsylvania
Primary fields: Computer science; electronics and electrical engineering; physics
Primary invention: Electronic Numerical Integrator and Computer (ENIAC)

EARLY LIFE

John William Mauchly (MAHK-lee) was born in Cincinnati, Ohio, in 1907 but grew up in the Maryland suburbs of Washington, D.C. His father, Sebastion Mauchly, was a physicist in the Department of Terrestrial Magnetism of the Carnegie Institution in Washington. Mauchly was a precocious child with an early interest in electricity. When he was five years old, he built a flashlight from a battery and a small bulb in order to explore a dark attic with a friend. While still in grammar school, he earned extra money by wiring electric doorbells and repairing electric wiring for his neighbors.

Mauchly attended a technical high school in downtown Washington where he thrived on mathematics and science. His grades were outstanding, and he still had time for sports and editing the high school paper. He graduated in 1925 and, for his high achievements, obtained an engineering scholarship to Johns Hopkins University. Mauchly entered Johns Hopkins with an electrical engineering major but soon found the courses too mundane and lacking in intellectual excitement. He found physics to be much more interesting, and in his second year he switched his field of study to physics.

Johns Hopkins had a program that allowed outstanding students to skip the final undergraduate years and enter graduate school to work toward a Ph.D. Mauchly took advantage of this and enrolled in graduate school to study physics after only two years as an undergraduate. He received his Ph.D. in 1932 with a thesis on molecular spectroscopy.

At the height of the Depression in 1932, it was very difficult for newly minted physicists to find jobs. Mauchly applied to a number of research institutions without success but finally received an offer from Ursinus College, a small liberal arts college in the outskirts of Philadelphia. Mauchly was the head and only professor of the Physics Department and quickly became an excellent teacher who could make the dull equations of physics come alive. He never lost his desire to do research, however, and in his spare time he became obsessed with predicting the weather. He bought a used desk calculator and, with weather data from friends in Maryland, attempted to predict weather patterns statistically.

Life's Work

Mauchly knew that a mechanical calculator would be far too slow to handle the huge number of variables needed to calculate the weather and that only vacuum tubes were capable of doing the job. He had built some simple electronic circuits at Ursinus, but he was frustrated by his inability to obtain funds and equipment to do research. He found that the nearby Moore School of Electrical Engineering of the University of Pennsylvania was offering a ten-week course in defense electronics and took the course in his spare time in 1941. The assistant in the course was John Presper Eckert, and the two of them found a common interest in computing and building a very high-speed computer. At the end of the course, Mauchly was offered a job as an adjunct professor in the Moore School and gladly accepted. This was the break he needed. With Eckert, he began to outline the plans for a large electronic computing machine.

The Electronic Digital Computer

John William Mauchly and John Presper Eckert were the first persons to build a workable electronic digital computer that was useful for solving mathematical problems. Mauchly was a physicist who wanted to predict the weather but found that all of the calculators available were orders of magnitude too slow to handle the huge amount of data needed to carry out the task. Others had built computing machines that could solve mathematical problems or operate on large amounts of data, but they were very slow and the results often had high uncertainties. Mauchly teamed up with Eckert, an engineer, and built the first usable electronic digital computer to calculate firing tables for Army artillery.

Their Electronic Numerical Integrator and Computer, ENIAC, consisted of thirty units, twenty of which were essentially ten-digit adding machines. The other units could multiply, divide, take square roots, and perform certain logic functions. The final computer contained 17,468 vacuum tubes and could do five thousand additions or fourteen ten-digit multiplications per second. It was programmed with patch cords and switches, so changing programs was very difficult.

This downtime between operations when the patch cords and switches had to be reset led to the next important invention. While the ENIAC was still under construction, Eckert and Mauchly planned a new computer that would do away with most of the cords and switches by including a memory that could remember the different setups and switch the programs as they were needed. They obtained funding for this stored program computer, which they named the Electronic Discrete Variable Automatic Computer (EDVAC), but did not finish construction before they left the Moore School of Electrical Engineering to set up their own computer company.

It was the development of the Universal Automatic Computer (UNIVAC) by Eckert and Mauchly and its use to successfully forecast Dwight D. Eisenhower's victory in the 1952 presidential election that increased public interest in the electronic digital computer and led to the quick expansion of the industry. Eckert and Mauchly showed that the electronic digital computer was a reality and could be used in dozens of different applications in which high-speed calculation was needed. With the additional inventions of the transistor and the computer chip, powerful computers can now be carried around in a briefcase and used practically anywhere on the planet.

The Moore School had a contract with the Army's Ballistics Research Laboratory to produce firing tables for the many new field artillery pieces being built. These tables were produced by female "computers" using a large analog computer and mechanical calculators. Mauchly wrote a memo in 1942 outlining a general-purpose electronic digital computer that could calculate the firing tables faster and more accurately than the methods being used. The memo was forgotten until a young mathematician at the Ballistics Research Laboratory became interested in it and encouraged the Moore School to submit a proposal based on the memo. The proposal was submitted in April, 1943, and Project PX, which later became the Electronic Numerical Integrator and Computer (ENIAC), was born.

Eckert was the principal project engineer, and Mauchly, because of his teaching responsibilities, could act only as a consultant to the builders. The computer was a parallel machine with thousands of vacuum tubes that could do several operations simultaneously and calculate one thousand times faster than the methods used at that time. The only drawback of the machine was that to change programs sometimes required up to a day to reset hundreds of patch cords and switches.

The ENIAC was completed in February, 1946, and turned over to the Army. World War II was over by then, but the Cold War with the Soviet Union was heating up and the

Army had many other uses for the computer. ENIAC was moved to Army facilities in Aberdeen, Maryland, and used in the development of the hydrogen bomb and in other military projects for the next eight years.

As early as 1944, Eckert and Mauchly recognized the difficulty in changing programs on the ENIAC and started to design a second machine with a memory that could take over the functions of many of the patch cords and switches and also store data. In January, 1945, a contract was procured to build a stored-program computer called the Electronic Discrete Variable Automatic Computer, or EDVAC.

Before the EDVAC was completed, Mauchly and Eckert resigned from the Moore School after a dispute over patent policy and established their own company, the Eckert-Mauchly Computer Corporation (EMCC). Unfortunately, the company was undercapitalized and had trouble finding buyers for its computers. Its major sale was of a new computer, the Universal Automatic Computer, or UNIVAC, based on the EDVAC design. The company was sold to Remington Rand in 1950, and Eckert became head of the UNIVAC Division. Mauchly consulted for the company on computer applications but left in 1959 to establish his own consulting company, Mauchly Associates. In the late 1960's, he established another company, Dynatron, which consulted on project planning and management techniques such as the critical path method.

Mauchly's last few years were saddened by the invalidation of his patent for a general-purpose electronic computer. He and Eckert had applied for a patent on the ENIAC in 1947 and it had been granted in 1964, but a physicist from Iowa State College, John Vincent Atanasoff, had come forth and claimed that many of the ideas in the ENIAC were his. Mauchly had visited Iowa State in 1941 and had seen pieces of an electronic computer that Atanasoff was building, but he claimed that the ENIAC was nothing like the pieces he had seen. Although the Atanasoff computer was never completed, a judge ruled in 1973 that John Atanasoff was the inventor of the electronic digital computer and the Eckert-Mauchly patent was not valid.

Mauchly received many honors, including election to the National Academy of Engineering and honorary doctorates from the University of Pennsylvania and Ursinus College. He was also made a life member of the Franklin Institute and the Society for the Advancement of Management. His awards included the Pennsylvania Award, the Emanual R. Piore Award, and the Potts Medal. Mauchly retired to his suburban home in Ambler, Pennsylvania, and lived quietly until his death in 1980 at the age of seventy-two.

Impact

Mauchly and John Presper Eckert will be remembered for their three great contributions—the first all-electronic general-purpose digital computer, the first stored-program computer, and the first commercial computer company. The ENIAC was the forerunner of the millions of electronic computers used in the world today. It was originally designed by Mauchly and Eckert to solve mathematical problems, but it was found to be so versatile, with so many applications, that it changed the world.

Electronic computers are now used in every aspect of communication and control throughout the world. Instead of writing letters with a pen or a typewriter, people type up an e-mail and push the Send button, and the message arrives instantaneously. Instead of doing research by going to the library and reading a book or journal, students often go to Google to find the information they need. By the year 2000, 60 percent of the homes in the United States had one or more computers. Today the percentage is even higher.

The microprocessor, a small, single-purpose computer, has even more applications than a general-purpose computer or a personal computer (PC). It controls the engines of cars, it tells an elevator where to start and stop, and it controls digital cameras and edits pictures before they are printed. A complicated machine such as an airplane or space vehicle has hundreds of microprocessors that navigate and help control its engines. In general, computers have made modern life easier and more fruitful.

—*Raymond D. Cooper*

Further Reading

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See also: John Vincent Atanasoff; Charles Babbage; John Bardeen; Clifford Berry; Seymour Cray; John Presper Eckert; Gottfried Wilhelm Leibniz; George Stibitz.

HIRAM PERCY MAXIM

American mechanical engineer

Maxim's varied career included work in aviation, the automobile industry, communications, and acoustics, and he is best known for his invention of the silencer. His innovations in automobile design provided the essential structure of the modern automobile, and he was a champion of the rights of amateur radio broadcasters.

Born: September 2, 1869; Brooklyn, New York
Died: February 17, 1936; La Junta, Colorado
Primary fields: Automotive technology; communications; mechanical engineering
Primary inventions: Automobile design; Maxim silencer

EARLY LIFE

Born in 1869, Hiram Percy Maxim was the only son of Hiram Stevens Maxim, a pioneer in electrical technology and aviation. The elder Maxim's most famous invention was his Maxim gun, the first portable, fully automatic machine gun. His invention earned him wealth, social standing, and (after he became an English citizen) a knighthood. His brother, Hudson Maxim, was also an inventor, specializing in high explosives.

Growing up in such an inventive household, Hiram Percy Maxim soon developed a great appreciation of the technological arts, and he strove to live up to the family name. Attending public schools in Brooklyn, Maxim was so bright that he skipped several years of schooling and graduated early. He was accepted at the prestigious Massachusetts Institute of Technology (MIT), the leading electrical and mechanical engineering institution in the country. He again engaged in an accelerated program, graduating from MIT in 1886. Unfortunately, his father was not there to celebrate his success. The older Maxim, after losing a patent battle over the light bulb with Thomas Alva Edison, had moved to England and was already perfecting his machine gun designs. Unwilling to move to Europe, despite his father's offer to financially support his projects and education, the younger Maxim chose to stay in the United States. The father and son never saw each other again, but they maintained correspondence until the father died in 1916.

LIFE'S WORK

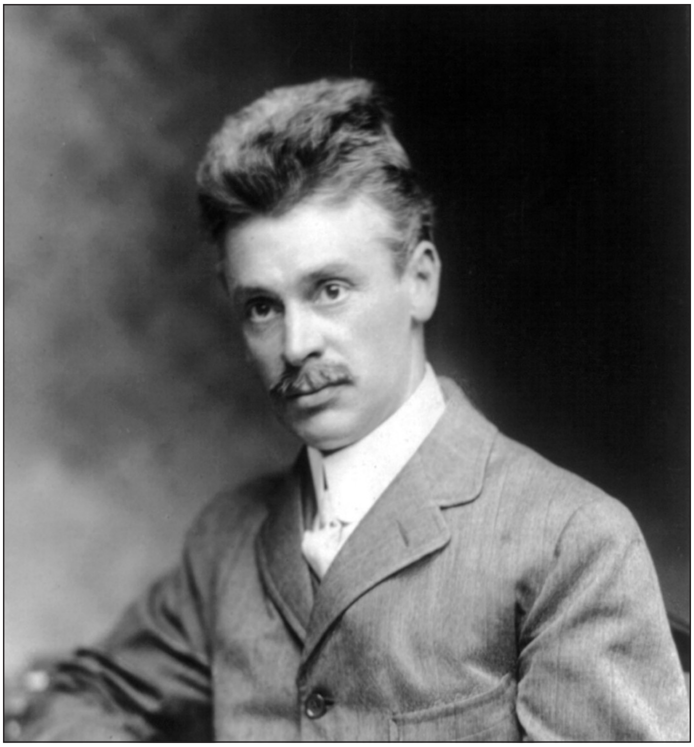
At MIT, Maxim became interested in aviation. He designed and tested several gliders and continued the experiments after he had graduated and moved to Hartford, Connecticut. In 1889, he crashed one of his gliders, badly injuring his right leg. The incident ended his flying days, but not his interest in aviation. Of the fifty-nine patents Maxim received during his career, several were for aircraft navigation and instrumentation devices. He also served on the planning board for construction of Brainard Field (now Hartford-Brainard Airport), one of the first municipal airports in the country.

Maxim also experimented in noise suppression, an interest sparked by his father's work. After years of subjecting his ears to the loud bang of bullet firings, the elder Maxim was almost completely deaf by 1895. Although it was too late for his father, the younger Maxim wanted to prevent hearing loss for others. His solution was the Maxim silencer, a device for reducing the noise of a gun firing. His invention slid onto the end of a firearm and used internal baffles to muffle the sound produced by the combustion of the ammunition propellant. It was not a true silencer, however: It reduced the noise produced by the bullet firing but could not suppress the cracking noise when the bullet passed the sound barrier after leaving the barrel. After demonstrating his concept on firearms, Maxim later adapted his basic design to other applications, such as mufflers for automobiles and sound suppressors for factories. In 1930, Maxim patented a "window silencer," a device that fit into an open window that permitted airflow but blocked exterior noise. Thanks to these inventions, Maxim is considered one of the pioneers of the science of acoustics.

Maxim made some of his greatest contributions in the automotive field. He first became interested in automobiles while at MIT, where several of his colleagues postulated the use of electricity for propulsion. He set aside the issue for several years after he graduated while working at engineering jobs in Indiana and Massachusetts. In 1890, Maxim became the operating superintendent of the American Projectile Company, a maker of munitions for the Army and Navy located in Lynn, Massachusetts. Commuting six miles between Lynn and his home in Salem every day by bicycle soon convinced Maxim that a more efficient mode of transportation would be a good idea, and he began to think again about electrically powered transportation. His plans and experiments brought him into contact with Albert Augustus Pope, a bicycle manufacturer in Hartford interested in getting into the automobile industry. Merging their ambitions, the two men founded the Pope Manufacturing Company in 1895, whose motor vehicle division became the Columbia Automobile Company in 1899. Their first electric car, promoted for its safety compared to the potentially dangerous gasoline-powered cars of the day, was sold in the United States, Canada, France, and the United Kingdom. As gasoline engines became safer, Maxim and Pope changed their designs to accommodate the new technology. Their first gasoline-powered car, introduced in 1900, set the design standard for most automobiles. It was the first automobile with a front-mounted engine (early cars had the engine under the driver's seat) and a steering wheel on the left-hand side of the car (early cars had a centrally mounted tiller).

The Columbia Automobile Company went through several business manifestations as it acquired and merged with rival car companies. The company was able to defeat and acquire its rivals because it possessed the rights to the Selden patent (named for automobile inventor George B. Selden), which allowed Albert Pope to collect royalties from all manufacturers of internal combustion engine vehicles. The Columbia Automobile Company had purchased the rights to the patent and used it to suppress competition. Pope sold his shares in the company in 1903, leaving Maxim as the managing director. Henry Ford was beginning to dominate the automobile industry, however, and in 1911 Maxim also left the company, a few years before the firm went out of business. That year, Ford was able to convince the courts to overturn the Selden patent on the automobile, and his more efficient production systems made him the leading figure in the automobile industry.

Maxim's other great impact was in radio communications. He understood the potential impact of instantaneous communications and received several patents for improved transmitters and receivers. His biggest contribution to radio, however, was his organization in 1914 of the American Radio Relay League (ARRL). With radio in its commercial infancy, Maxim became concerned that government and business might attempt to close the industry to amateur and independent radio transmitters. Maxim and the ARRL defended the rights of independent radio



Hiram Percy Maxim. (Library of Congress) operators to use the airwaves. The ARRL created a network across the country that could relay information rapidly from coast to coast, something that single powerful transmitters of the day could not do. The same relay principle is used today to transmit cellular phone calls.

During the world wars, the U.S. government shut down the ARRL to free the airwaves for military transmissions, but the ARRL reclaimed the right to transmit after each war ended. Maxim created a set of operating guidelines to ensure the professional and ethical standards of the organization. The guidelines made amateur radio respectable, and its high standards ensured that the organization enjoyed a long life.

AUTOMOBILE DESIGN

Hiram Percy Maxim's solutions to automobile technical problems provided the essential structure of the modern automobile. First, he created the standard exterior appearance. Early automobile makers either made their own chassis or used existing companies', usually wagon or carriage makers. Early cars were called "horseless carriages" because, indeed, they looked like carriages. The engines were located inside the chassis, usually under the driver's seat. This design made the vehicles unstable on rough roads. When Maxim and the Columbia Automobile Company switched from producing electric cars to producing internal combustion engine models, he had the engine placed in front of the chassis. This both lowered and balanced the center of gravity, making the cars more stable and safer to drive.

Maxim also pioneered the left-mounted steering wheel. Early cars had a steering tiller or a wheel centrally mounted on the front axle. This was another holdover from a horse-drawn carriage, in which the driver needed to sit up front to control the horses. However, this arrangement also made it difficult for the driver to look over either shoulder to view other vehicles. By moving the wheel to the left-hand side of the vehicle, Maxim created a safer mode of driving. The left-side steering wheel became the norm when Henry Ford began building only left-side steering automobiles in 1908. Maxim completed the shape of the modern automobile by equipping the vehicle with items that became standard. He installed the first electrically powered headlights, a turn signal, an electric starter, and a muffler to quiet the loud engine. He even installed a seat belt, the first universal safety device in an automobile.

In 1936, Maxim fell ill while returning home by train from a trip to California. He was taken to a hospital in La Junta, Colorado, where he died on February 17. To honor Maxim's role in creating the organization, the ARRL granted him the call sign 1AW, marking him as the first amateur radio operator.

IMPACT

The son and nephew of famous inventors, Maxim was an important inventor in his own right. His inventive genius touched on many of the early technologies that shaped the twentieth century: flight, electricity, the automobile, and telecommunications. His Maxim silencer brought him fame, and he applied its principle to mufflers for gasoline engines. Through the American Radio Relay League, Maxim championed the rights of amateur radio operators.

—*Steven J. Ramold*

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Maxim, Hiram Percy. *Horseless Carriage Days*. New York: Harper & Brothers, 1937. Details Maxim's activities in the early years of the automobile industry, exploring the era in which electric cars vied with internal combustion engine models.

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Schumacher, Alice Clink. *Hiram Percy Maxim: Father of Amateur Radio, Car Builder, and Inventor*. Cortez, Colo.: Electric Radio Press, 1998. The only single-volume biography of Maxim, the book is a relatively brief but full account of Maxim's varied career, with an emphasis on his contributions to radio.

See also: Lewis Howard Latimer; John William Mauchly; Hiram Stevens Maxim; Hudson Maxim; John T. Thompson.

HIRAM STEVENS MAXIM

American electrical engineer

Although generally known as an inventor of war machines, Maxim was also an inventive genius whose developments in aerospace might have changed history if he had pursued them.

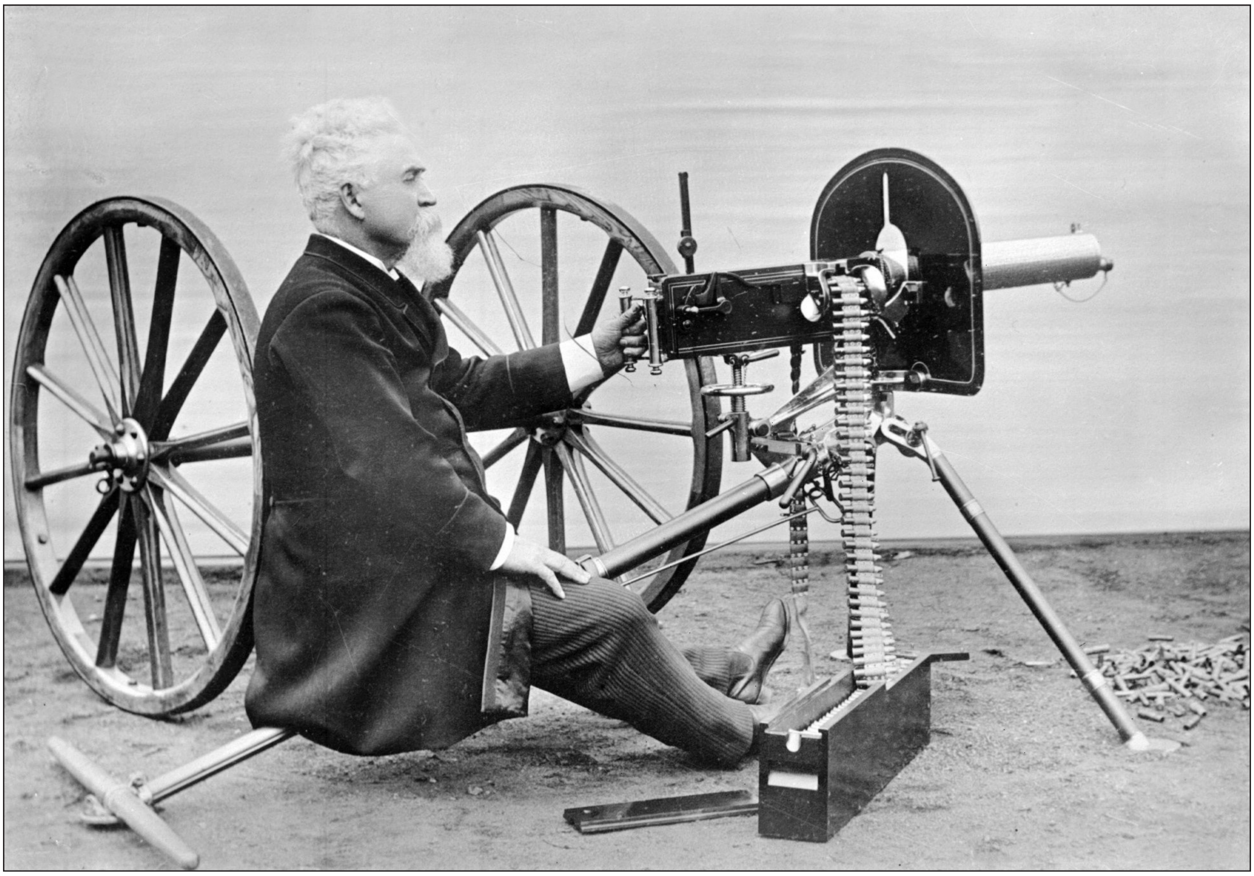
Born: February 5, 1840; Sangerville, Maine
Died: November 24, 1916; London, England
Primary fields: Aeronautics and aerospace technology; military technology and weaponry
Primary invention: Recoil-operated machine gun

EARLY LIFE

Born in Maine, Hiram Stevens Maxim was the oldest son of a mechanic employed by the growing railroad industry. Following in his father's footsteps, Maxim apprenticed with a carriage maker until the age of twenty, when he set out to find his own place in the world. Among his early inventions was a spring-loaded mousetrap, the same basic design still used today.

Tinkering with electricity led to other inventions. In 1866, Maxim received a patent for an electrically heated device to curl hair, the curling iron. He also developed products for the railroad industry, including an improved locomotive headlamp. Early lamps used heated gas to produce illumination, and Maxim devised a machine to separate gas elements, allowing for cheaper bulbs and lamps at a time when both were very expensive. These inventions attracted the attention of the United States Electric Lighting Company (USEL), which hired Maxim as its chief engineer. USEL was in the process of developing, patenting, and marketing electric lighting for homes and businesses, and the company set Maxim to create more efficient filaments and bulbs.

By 1880, Maxim had created an improved design, but



Hiram Stevens Maxim with his machine gun in 1880. (Roger Viollet/Getty Images)

THE MACHINE GUN

Hiram Stevens Maxim was the inventor of the first practical machine gun. He recalled when, as a boy, the recoil of a rifle knocked him backward, and he pondered over a way to harness that backward force to power a weapon. Renting a country home outside London, Maxim designed, constructed, and tested a recoil-operated machine gun. The gun used the simple principle of recoil to do a number of complex tasks. When the gun fired, the recoil opened the breech, ejected the spent cartridge, and compressed a spring. The stored energy in the spring then drove the bolt forward again. The forward-moving bolt turned a cog, which drew the next bullet into alignment with the bolt so that the bolt pushed it into the breech when the bolt closed shut. Then the firing pin located in the bolt fired the new bullet, and the process started all over again. Because the gun went through this cycle without human intervention, Maxim had invented the first true machine gun. Like a machine, the gun was turned on when the trigger was pulled, and as long as the trigger remained pulled, the gun would continue to fire. The only way the gun stopped firing was when the operator released the trigger or no more bullets were left.

Maxim's weapon, which improved upon earlier hand-cranked Nordenfelt and Gatling guns, could shoot longer, farther, and with more accuracy than the earlier designs. Using cartridges of his own design, Maxim and his gun could throw out many more bullets than any other gun available at the time. Many armies adopted his weapon, and the machine gun became the centerpiece of infantry forces around the world. The gun first gained infamy when European nations used the Maxim gun to destroy native armies in their push to gain colonies around the world in the late nineteenth century. It became even more infamous when the Europeans used their Maxim guns on each other in World War I, generating massive numbers of dead and wounded over the course of the war.

his work for USEL came into conflict with Thomas Alva Edison. Edison had applied for a patent for the light bulb in 1879, and he believed that Maxim's bulb infringed upon his patent. Edison and Maxim sued and countersued each other for nearly a decade, until the courts ruled in Edison's favor in 1889. With the American patent in Edison's hands, Maxim moved to England to market his electrical system, where Edison's American patent had no leverage. Maxim continued to invent and market electrical devices of his own design, featuring them at technical exhibitions in various European countries.

LIFE'S WORK

Maxim was motivated to create his greatest invention while attending one such technical exhibition in Vienna. He ran into an old friend from America, who inquired about Maxim's inventions and business interests. After listening to Maxim's sales pitch on his electrical devices, Maxim's friend instead encouraged him to go into weapons research. The rise of Germany after 1870 was causing a great amount of political tension in Europe, and countries were increasing the size of their armies and spending money on new weapons as the threat of a potential war seemed to grow. Maxim, mired in his patent fight with Edison, decided to take his friend's advice and set about developing a rapid-fire gun. Guns that could fire a large number of bullets very quickly had existed for a couple of decades, but their designs had some drawbacks. The Swedish-designed Nordenfelt gun used four barrels side by side, a clumsy arrangement. The American-designed Gatling gun used six barrels that rotated around a central shaft but had a better arrangement; it was, however, very heavy. Both guns fired when the operator turned a crank that fed rounds by gravity from a hopper, making both guns rapid-firing, but not true machine guns.

At first, Maxim tried to create an electrically driven weapon, but he found that approach to be impractical. Eventually he devised a true machine gun using the principle of recoil. Maxim's design was not only simple; it also was very reliable. Under ideal conditions, the gun could fire six hundred bullets in one minute. The gun did produce a large amount of smoke, but Maxim later redressed this in 1891, when he invented a smokeless powder cartridge for the weapon. Maxim patented the gun in 1885 and formed the Maxim Company in 1886 to market the gun to European armies. After a series of demonstrations—including an impressive demonstration for the Prince of Wales (the future King Edward VII), when Maxim fired the prince's initials into a wooden wall two hundred yards away—the British army adopted the Maxim gun in 1889. Within the next three years, Maxim also saw his gun adopted by a number of armies, including those of Austria, Germany, Italy, Japan, Mexico, and Russia. The United States did not adopt Maxim's gun, instead selecting another model produced by the Colt Firearms Company.

Maxim's company became so lucrative that Vickers & Sons, one of England's largest defense companies, offered to buy him out in 1896. Maxim received a large cash payment for the rights to his patent, a seat on the board of directors, and a fee for every gun sold by Vickers. In honor of the new arrangement, Vickers changed its company name to Vickers, Son & Maxim. Grateful to Great Britain for helping to make his fortune, and still angry that he had lost his patent fight with Edison in America, Maxim became a British citizen in 1899. As a reward for his contributions to the defense of Great Britain, Maxim was knighted in 1901.

While Maxim's machine gun made him famous (or infamous, as all combatants in World War I used copies of his gun to kill each other by the tens of thousands), he was also a pioneer in aviation development. Although Maxim was forced to devote considerable effort to his machine-gun interests over the next years, he began to devote time to aviation in 1889. To test various aircraft designs, most aircraft pioneers relied upon different versions of the wind tunnel, where a model remains stationary and air is blown over the model's control surfaces to see how the aircraft performs. Maxim took a different approach. With his "captive flying machine," he attached models to a suspension rig attached to a spinning frame powered by a steam engine in the center. Maxim could then observe the characteristics of the aircraft model as it moved through the air in the wind tunnel.

The development of this test rig provided another lucrative outlet for Maxim's creativity. He built a larger version of the test rig with cars big enough for people to ride in, creating an amusement ride. Maxim installed his first ride at an exhibition near London at Earl's Court. It was an incredible success, with long lines of patrons willing to spend their money to whiz around in simulated flight. Maxim had made a major contribution to the development of the amusement park, and other inventors soon copied the idea.

Using the aerodynamic information from the test rig, Maxim constructed his first airplane in 1894. It was a massive craft, with two large wings more than 100 feet in length and weighing more than 7,000 pounds. By comparison, the successful Wright brothers aircraft of 1903 had a wingspan of just over 40 feet and a weight of 605 pounds. Maxim had to construct an aircraft that large because of the power plant. His plane was powered by two powerful but bulky steam engines, but these were the best available (lightweight internal combustion engines were still a decade away). On July 31, 1894, Maxim, along with three other men to assist with the flight controls, attempted his first flight. The aircraft surged down an 1,800-foot launch rail, reached an estimated speed of 42 miles per hour, and rose about 15 feet into the air. The craft flew about 200 feet before the engines sputtered and the craft crashed back to earth.

Maxim had to turn his attention to other projects, and he did not return to aviation until 1911, when he partnered in the Grahame-White, Bleriot, and Maxim Company to develop aircraft for military purposes. By that time, however, Maxim was trying to catch up in an existing industry and was no longer the pioneer. The company failed to achieve any technical or commercial success. Later in life, Maxim developed some lesser-known patents that remain in use today, including a pocket menthol inhaler, similar to the pocket inhalers used by asthma sufferers.

Impact

Although a prolific inventor, Maxim remains best known as the inventor of the machine gun. He could not have known what carnage his invention would create in subsequent wars, but he always tried to separate himself from his invention. Unfortunately, the Maxim machine gun, used by all sides during World War I, killed tens of thousands in that conflict, and improved versions of Maxim's design have served in all wars since then. The machine gun remains the dominant infantry weapon in every army's arsenal, and every improvement and development of the machine gun stems from Maxim's pioneering design.

—*Steven J. Ramold*

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Ellis, John. *The Social History of the Machine Gun*. New York: Pantheon, 1975. Starting with Maxim's creation of the first practical weapon, this book depicts how the machine gun has been viewed by the armies that use it and the cultures that are protected by it.

Goldsmith, Dolf G. *The Devil's Paintbrush: Sir Hiram Maxim's Gun*. Toronto: Collectors Publications, 2002. A full history of the development and introduction of the Maxim gun into the arsenals of the world's armies at the turn of the century, although the book is aimed more at enthusiasts and collectors. Goldsmith documents the use of the Maxim gun as an instrument of European imperialism, and its deadly impact upon World War I.

Hawkey, Arthur. *The Amazing Hiram Maxim: An Intimate Biography*. Stapelhurst, England: Spellmount, 2001. Hawkey covers all of Maxim's major inventions throughout his career, somewhat downplaying Maxim's development of the machine gun. Altogether, the text is a better tribute to Maxim than to history, but it is nevertheless an excellent survey of Maxim's entire inventive career.

Maxim, Hiram S. *Artificial and Natural Flight*. London: Whittaker, 1909. In this book, Maxim postulates on the future of powered flight and makes the case that his steam-powered biplane of 1894, and not the Wright brothers' aircraft, should be considered the first successful airplane.

See also: John Moses Browning; Glenn H. Curtiss; Henry Ford; Alfred J. Gross; Hiram Percy Maxim; Hudson Maxim.

HUDSON MAXIM

American chemist

The brother of machine-gun inventor Hiram Stevens Maxim, Hudson Maxim invented several types of explosives, the most important of which was smokeless gunpowder, which is now used in all modern firearms.

Born: February 3, 1853; Orneville, Maine
Died: May 6, 1927; Landing, New Jersey
Also known as: Isaac Maxim (birth name)
Primary fields: Chemistry; military technology and weaponry
Primary invention: Smokeless gunpowder

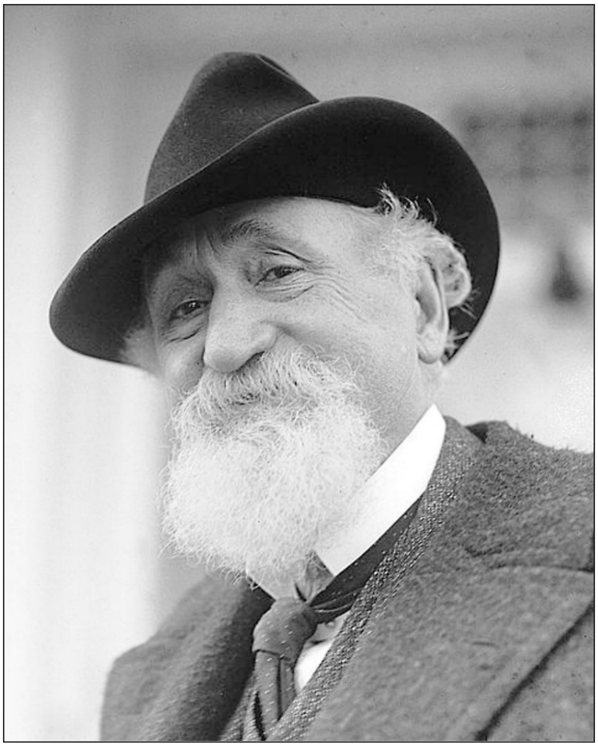
EARLY LIFE

One of eight children of a poor family in rural Maine that frequently relocated, Hudson Maxim did not attend school until he was eight years old and did not even wear shoes until he was nine. To earn money for schoolbooks when he was young, he pitched hay on farms, pounded rocks in a granite quarry, and worked in a brickyard. Like his parents, he was exceptionally strong and very hard-working.

At the age of eighteen, Maxim enrolled at Maine Wesleyan Seminary, a coeducational college-preparatory school in Kents Hill that was later renamed Kents Hill School. He attended the school several weeks of each year for seven years, spending the rest of his time earning money to pay for it. When he was twenty, he took a job as a schoolteacher for one term a year and began in a classroom filled with unruly boys who had thrown their last teacher out a window. Maxim later admitted that at that time, he knew little more than his pupils did. However, he learned quickly enough to stay ahead of them and imposed order in the classroom after defeating the toughest boy in a wrestling match.

When he was twenty-two, Maxim hypothesized that all matter is composed of a single type of ultimate atom, and that differences in complex matter are due to the differing arrangements and motions of the atoms' component. In 1889, *Scientific American Supplement* published an article he wrote explaining his theory. When *Scientific American* reprinted the article in 1921, the magazine credited him with anticipating some aspects of Albert Einstein's atomic theory.

Meanwhile, Maxim had moved to Pittsfield, Massachusetts, where he set up a publishing business in 1883. He wrote a self-help book, *The Real Penwork Self-Instructor for Penmanship*, which his own company published. The book sold more than 400,000 copies, and his business grew large enough to employ one hundred people. However, the rise of typewriters and fountain pens killed the market for his book. Maxim also invented a



Hudson Maxim. (Library of Congress)

color-printing process that Pittsfield's *Evening Journal* used to become the first U.S. newspaper with daily color pages.

LIFE'S WORK

In 1888, Maxim received a request from his older brother Hiram Stevens Maxim, then living in England, to hire some American workers for his gun company. At that time, Hiram was making a fortune from his automatic machine gun, which became known as the Maxim gun. Hudson took a mechanic and draftsman with him to England, where he went to work for his brother. He and Hiram worked together on many projects, including smokeless gunpowder.

After returning to the United States, Maxim continued his own experiments with explosives and founded the Maxim Powder and Torpedo Company in Squankum, New Jersey—a town that was later renamed Maxim in his honor. Based on nitrocellulose, his smokeless gunpowder became the standard for U.S. Army guns. Maxim's claim that his formula for smokeless gunpowder was his own invention started a bitter feud with his brother. His own formulation was, in fact, different from that of his brother, but neither of them was actually the original inventor of smokeless gunpowder. What they had both done was reverse-engineer a smokeless powder sample that had come from a French government armory.

Maxim next turned his attention to developing smokeless cannon powder. The smokeless cannon powders available at that time were made in the form of flat strips, ribbons, or rods with one perforation. The grains burned when they came into contact with sulfur and charcoal particles, so the powder burned relatively slowly, and pressure decreased significantly as projectiles reached the forward part of the cannons' barrels. Maxim devised a smokeless cannon powder cylinder that was three times as long as it was wide. Each unit was perforated with seven longitudinal holes. These holes allowed the cannon powder to burn evenly and rapidly, producing more ballistic force.

In 1894, Maxim lit a match to test the dryness of a small particle of mercury fulminate compound, forgetting that he was holding another piece of the compound in his left hand. The second piece ignited and blew off his entire hand, leaving the end of his wristbone exposed. His left thumb landed two hundred yards away. He eventually adapted very well to his handicap; he grew

MAXIMITE

Composed of mono-nitro-naphthaline and picric acid, maximite is rated as a high explosive because the velocity at which the detonation propagates through the compound is faster than the speed of sound. Maximite has about 50 percent greater explosive power than an equivalent quantity of dynamite. Even more important, it is extremely stable. Under heat, it simply boils. When it ignited, it burns without exploding.

Maximite's fusion point is below the boiling point of water. Accordingly, it can be safely melted over an open fire and then poured into a projectile. Like water, liquid maximite expands slightly when it solidifies, and it also adheres to the walls of the projectile. These characteristics are among the reasons that it is inexpensive to manufacture.

According to Hudson Maxim's description, after maximite solidifies within a projectile, it remains so stable that it is not disturbed even by the projectile's impact and penetration through an armor plate. It detonates only when a fuse sets it off. Before maximite was used, shells containing high explosives that were fired from cannons had to be fired at relatively low velocities, lest the impulse of the propellants inside the cannon barrels accidentally detonate the explosives within the shells. Maxim promised that using maximite as a high explosive would greatly reduce the risk of accidental detonation. Accordingly, a shell loaded with maximite could be shot with tremendous force, tremendously increasing the shell's range and penetrative power.

Despite the amount of energy that maximite contains, it is a lightweight compound. Accordingly, relatively small cannons firing maximite shells could hit targets at great distances using only small amounts of propellant. The compound's light weight also facilitated the transportation of greater quantities of shells.

When high explosives detonate on hard surfaces—such as armor plates or paved street—much of their energy simply bounces off the surfaces. Thanks to its stability, maximite does not detonate until its shells penetrate the surfaces. Consequently, its explosive energy is directed into the interior of the enemy targets and causes vastly more damage than explosives that detonate on the outside surfaces of ships, buildings, and other armored structures.

At the time Maxim invented maximite, many naval engineers believed that an unsinkable battleship could be built. Maximite made that dream impossible, although many people at the time did not know this. However, despite maximite's many advantages, the U.S. military abandoned its use after a premature detonation of 143 pounds of the compound in a torpedo shell demonstrated that Maxim's formulation was not yet perfected.

skilled at using the hook that replaced his lost hand and was not shy about gesturing with it as one would with a hand.

Meanwhile, Maxim's first marriage, in Pittsfield, ended in divorce after five years. In 1896, he married Lilian Durban, the daughter of a nonconformist London pastor and magazine writer. Like her husband, Lilian had a special interest in poetry, and she worked with him in their home laboratory in Brooklyn, New York. In 1898, Maxim sold his factory and patents to E. I. du Pont de Nemours and Company, for which he worked his remaining years as a consulting engineer.

Another of Maxim's major inventions was maximite, an explosive designed for use in artillery. (His brother Maxim used the same name for his own smokeless gunpowder, an unrelated product.) In 1901, the U.S. Army bought the exclusive right to use maximite from Maxim. Maximite needed delayed-action detonating fuses to work in artillery shells, so it could be activated after the shells penetrated enemy armor. Maxim invented the fuse, which in 1908 the U.S. Navy adopted.

In 1905, Maxim sold stabillite, an improved smokeless gunpowder, to du Pont. Earlier versions of smokeless gunpowder had to be dried for months before they could be used to give the volatile solvents left over from the manufacturing process time to evaporate. Because stabillite used no volatile solvents, it could be used immediately.

Among Maxim's other important inventions was motorite, a fuel for torpedoes and torpedo boats that he called his most difficult invention. Five feet long, seven inches in diameter, and dense and rubbery, each motorite bar was inserted in a steel tube. Each tube was open at one end, which was screwed to a combustion chamber. When a bar was ignited, water was pumped into the chamber and turned to steam by the motorite's heat. A series of baffles directed the steam out the combustion chamber. The combustion of the motorite combined with steam power to propel the torpedo, approximately doubling the amount of energy used by self-propelled torpedoes. In 1912, Maxim gave the rights to motorite to the U.S. Navy for one dollar, but the Navy never used it. Maxim also invented an improved process for producing calcium carbide that was bought by the Union Carbide Company.

After the United States entered World War I in 1916, Maxim chaired the Committee on Ordnance and Explosives for the Naval Consulting Board. He also worked on military inventions, including an underwater mine that was detonated by the magnetic field emitted by submarines that approached within fifty feet. That invention he donated to the U.S. government.

Although Maxim rested only reluctantly, he enjoyed spending time at his country estate at Lake Hopatcong, New Jersey. However, he had a working laboratory at his estate, which was only three miles from his Squankum factory. The loss of his left hand did not dampen his enthusiasm for physically exercise, especially playing tennis. Maxim twice played the role of King Neptune to open the Miss America Pageant in Atlantic City. Sporting a full beard, he rode a seashell barge and was surrounded by mermaids.

Maxim was also a serious lecturer and writer who promoted women's rights and opposed alcohol prohibition, which he called a national calamity. In April, 1926, he testified before a subcommittee of the Senate Judiciary Committee on the harm caused by the Prohibition laws and extolled the benefits of moderate alcohol consumption. He argued that people who abstain from alcohol tend to consume excessive amounts of sugars and starches in unconscious compensation for missing the stimulation and feeling of well-being produced by alcohol. A year later, when he died of cancer, on May 6, 1927, he was lauded by the press and revered by most of the public.

IMPACT

The importance of Maxim's development of smokeless gunpowder can be seen in its impact on battlefields. For centuries, smoke clouds discharged by black gunpowder revealed the positions of gunners to their enemies and often obscured the gunners' own vision. The creation of smokeless powder was especially important for the Maxim gun, which fired six hundred rounds per minute. It was also a welcome improvement for the Maxim gun's older American competitor, the Gatling gun. Smokeless powder is actually not a true powder; it takes its name from old-fashioned black gunpowder. It later became the standard for virtually all modern firearms. Even in guns with slow firing rates, it is cleaner and produces much less fouling in gun barrels, thereby helping to maintain accuracy and reduce malfunctions.

Maxim's development of a technique for manufacturing powder without use of volatile solvents became especially important during wartime, when rapid production was necessary. However, his own specific process was not used because one of its components, trinitroanisol, damaged human skin when the gunpowder was touched.

During World War I, Maxim's smokeless cannon powder was used extensively by the Allies, including the Russians. It allowed large guns to be fired more accurately and with higher muzzle velocities. It enabled guns to hit targets at greater distances and deliver greater destructive force. Artillery weapons killed more soldiers—on both sides—than did any other weapons in the war. Without Maxim's powder, the Allies would have been at a significant disadvantage.

—David B. Kopel

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McCallum, Ian. *Blood Brothers: Hiram and Hudson Maxim—Pioneers of Modern Warfare*. London: Chatham, 1999. Interesting parallel biography of two inventive geniuses, but sparse on the impact of Hudson's inventions and on the scientific details. Portrays Hiram as the greater inventor but sees Hudson as the brother who found greater happiness in his personal life.

Maxim, Hudson. *Defenseless America*. New York: Hearst's International Library, 1915. In this book, Maxim warned that a U.S. war with Germany was unavoidable and painted a vivid picture of the devastation of an unprepared America by invading armies. Maxim gave away 117,000 copies, and the book became the basis for a movie, *The Battle Cry of Peace* (1915), which like the book played a significant role in shaping American public opinion in favor of entry into World War I.

_______. *The Real Penwork Self-Instructor for Penmanship*. Pittsfield, Mass.: Knowles & Maxim, 1881. Maxim's book on penmanship that sold hundreds of thousands of copies and went through several editions during the 1880's.

_______. *The Science of Poetry and the Philosophy of Language*. 1910. Reprint. Whitefish, Mont.: Kessinger, 2007. Applies scientific theory to poetry and language by arguing that words, like atoms, behave according to certain natural laws, and that poetry is the most mechanically efficient form of communication.

Wildman, Edwin. *Famous Leaders of Industry*. 1925. Reprint. New York: Cosimo Classics, 2005. Collection of biographies of famous inventors that emphasizes their perseverance and other virtues in order to inspire young readers. The book includes an admiring and mostly accurate chapter on Maxim.

See also: Sir James Dewar; Hiram Percy Maxim; Hiram Stevens Maxim; Alfred Nobel.

DIMITRY IVANOVICH MENDELEYEV

Russian chemist

Mendeleyev's periodic table was one of the greatest achievements of chemistry in the nineteenth century. His table provided gaps for future elements, and he accurately predicted the properties of hitherto undiscovered elements.

Born: February 8, 1834; Tobolsk (now Tyumen Oblast), Siberia, Russia
Died: February 2, 1907; St. Petersburg, Russia
Primary field: Chemistry
Primary invention: Periodic table of elements

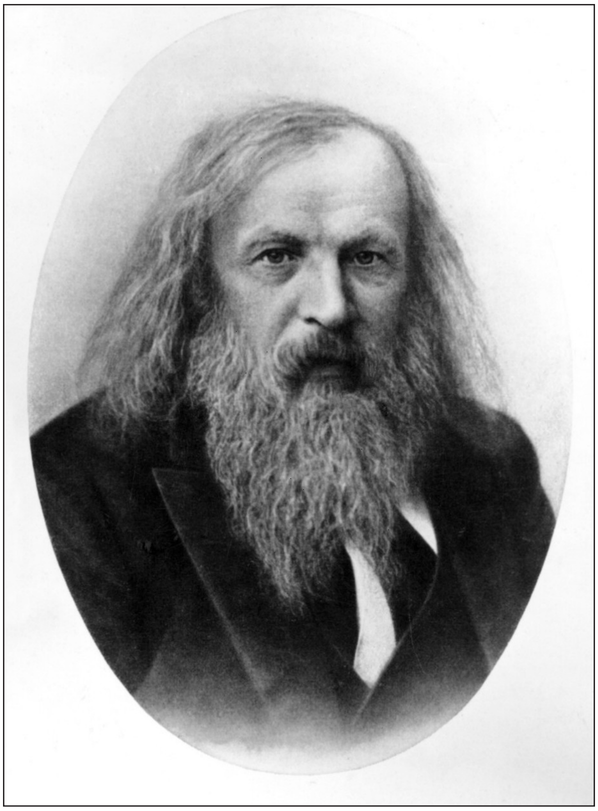
Early Life

Dimitry Ivanovich Mendeleyev (mehn-duhl-AY-uhf) was born on February 8, 1834, in Tobolsk in western Siberia. He was the youngest of fourteen (some sources say seventeen) children. His father, Ivan Pavlovich Mendeleyev, a headmaster of a local school, went blind after Dimitry's birth, so his mother, Maria Dmitrievna Mendeleyeva (born Kornilieva), had to work in their glass factory. Dimitry went to the local school where his father had taught but also received practical education at his mother's glass factory, where he spent hours listening to the chemist and the glassblower talk about glassmaking.

When Mendeleyev was a young teenager, his father died and the glass factory burned down. His mother was determined that Mendeleyev and her daughter Elizabeth (her other remaining dependent child) receive an education, so they traveled to Moscow and then to St. Petersburg. Mendeleyev was refused entry to St. Petersburg University because he was Siberian. In 1850, at age sixteen, he was accepted at the Central Pedagogic Institute of St. Petersburg to study science. Ten weeks later, his beloved mother died from tuberculosis, followed by Elizabeth. Mendeleyev studied diligently despite his personal tragedies. At age twenty, he published his first scientific article, "Chemical Analysis of a Sample from Finland," the first mark of an amazing young scientist. A year later, in 1855, he earned the Student of the Year Award from the institute, a well-deserved honor. After graduation, he obtained an advanced degree in chemistry and in 1857 received his first university appointment.

LIFE'S WORK

In the late 1850's, the Russian government tried to keep up with advances in science and technology, paying a number of Russian scientists, including Mendeleyev, to study in Europe. Between 1859 and 1861, he studied at the Universities of Heidelberg and Paris. During this time, he met leading scientists, including chemists Henri Victor Regnault (in Paris), Robert Wilhelm Bunsen, and Stanislao Cannizzaro and physicist Gustav Kirchhoff, learning such things as atomic weight and ways of determining chemical composition of substances, knowledge influential in his later work.



Dimitry Ivanovich Mendeleyev. (Getty Images)

Back in St. Petersburg, Mendeleyev continued to teach and found time to write. In 1861, he published *Organic Chemistry*, a prize-winning textbook that raised his standing in Russian chemistry education. In 1864, he was appointed professor of chemistry at the Technological Institute and married Feozva Leshcheva. They had a son, Vladimir, and a daughter, Olga. Their marriage was unhappy, and he eventually married Anna Ivanova Popova in early 1882, with his divorce finalized one month after remarriage. He had four children with Anna.

In 1867, Mendeleyev was made professor of general chemistry at St. Petersburg University, the institution that had rejected him seventeen years earlier. He was unable to find an appropriate textbook for his classes, so he began writing his own. The result was *The Principles of Chemistry*, volumes 1 and 2, which he wrote between 1868 and 1870. This book provided a framework for modern chemical and physical theory and was a best seller for many years. While writing the textbook, Mendeleyev stumbled on a discovery that would lead to his greatest achievement and ultimately transform the subject of chemistry: the periodic table of elements.

Other chemists had attempted to organize the elements by their properties. In 1803, English chemist John Dalton first developed the idea of atomic weight—the average mass of an atom of an element. Since then, other chemists—including Johann Wolfgang Döbereiner, William Odling, Julius Meyer, and John Alexander Reina Newlands—had tried to arrange the elements by atomic weight and looked for regular patterns in chemical properties of the atoms. In the mid-1860's, Newlands presented his idea of ordering the elements, which he christened the "law of octaves." His idea came very close to Mendeleyev's, but it was greeted with ridicule. Disheartened, Newlands gave it up and eventually retired from chemistry.

Mendeleyev was convinced that the order of the elements lay in their atomic weights. When he arranged the elements in an ascending order by atomic weight, he noticed that the chemical properties of the elements were already grouped into families. He realized that he had to leave gaps in his table for elements yet undiscovered. Further, he believed that he could predict the properties of the elements of those spaces. His predictions were proved right; as the elements gallium, scandium, and germanium were eventually discovered, his periodic table became a breakthrough in chemistry.

In the 1870's, Mendeleyev's periodic table was chal-

THE PERIODIC TABLE OF ELEMENTS

Dimitry Ivanovich Mendeleyev's classification of the chemical elements in a logical order was one of the greatest triumphs of chemistry. The periodic law is a fundamental principle in chemistry that enables chemists to understand the array of elements in the table. The law states that chemical elements show repeating ("periodic") properties when arranged in order of increasing atomic number to form the periodic table.

By listing the known elements and using their known atomic weights, Mendeleyev recognized repeating patterns. The elements were charted into rows (periods) and columns (groups) wherein every element had its place and the initial gaps were filled later with newly found elements. On the assumption that there was a pattern to the elements, Mendeleyev left blank spaces where elements seemed to be missing. The patterns in chemical and physical properties were all represented.

On February 17, 1869, Mendeleyev sat with a pack of sixty-three cards, inspired by the card game called patience (solitaire), in which cards are arranged horizontally by suit and vertically by number. He wrote the names and properties of the elements on each card and played "chemical solitaire," arranging the elements in horizontal rows called "periods" and vertical columns called "groups" and placing the elements in groups of seven. He organized them the same way as John Alexander Reina Newlands had arranged his periodic table a few years earlier, with the difference being that Mendeleyev's key property was the element's valency, the chemical-combining power of an element. According to Mendeleyev, the elements ranked from one to four on the valency scale.

As he plotted the valency against atomic weight, Mendeleyev found that the periods fell and rose much like Newlands's "law of octaves." Seven steps, taken in order of atomic weight, covered the elements from lithium (atomic number 3, valency 1) to carbon (atomic number 6, valency 4) and on to fluorine (atomic number 9, valency 1). He ran another seven steps to the next row, from sodium (atomic number 11, valency 1) to silicon (atomic number 14, valency 4) and on to chlorine (atomic number 17, valency 1). Somehow, the succeeding periods fell at each end in the same way as the first two periods, with more elements of the same valency in the middle.

The new system did not win immediate acceptance, but its greatness became apparent with time. In November, 1870, Mendeleyev described the properties of three hitherto unknown elements he named eka-aluminium, eka-boron, and eka-silicon. Within sixteen years, all three were discovered and named respectively as gallium (1875), scandium (1879), and germanium (1886)—conforming closely to his predictions. A half century later, the rationale of Mendeleyev's work gained a firm foundation in the concept of orbits presented by Danish physicist Niels Bohr, who relied on Mendeleyev's periodic table. By the mid-1950's, other discoveries had been made possible through the table's elemental relationships—for example, the discovery by James D. Watson and Francis Crick of deoxyribonucleic acid (DNA), the building block of life.

lenged by the scientific community, but eventually he won international renown. In 1882, he received the Davy Medal from the Royal Society of London. The periodic table paved the way for scientists to discover new elements. By 1898, the periodic table contained the "rare gases" discovered by Lord Rayleigh and William Ramsay, giving it eight groups instead of seven.

Mendeleyev continued to teach at the university after creating the table. He was a dedicated educator and wrote more than 250 science articles that appeared in journals and science magazines. One year before his death, he published "A Project for a School for Teachers" and "Toward Knowledge of Russia." Although he was a scientist, he took interest in politics and the state of Russia. His political activism got him into trouble, and he was forced to resign from his teaching post at St. Petersburg University in August, 1890; however, because Mendeleyev was a popular national figure, the government was obliged to find him other employment. In 1893, he was appointed director of the Bureau of Weights and Measures, a position he held until his death.

In 1905, Mendeleyev received the Copley Medal from the Royal Society of London and other honorary degrees from universities around the world. Two years later, while listening to a reading of Jules Verne's *Les Anglais au Pole Nord* (1866; *A Journey to the North Pole*, 1875), he died peacefully in his home. Today he is remembered as the Russian chemist who discovered the interrelationship between the chemical elements that transformed chemistry into a logical branch of science through his greatest achievement, the periodic table of elements. Though he was not awarded a Nobel Prize, he received a rare distinction when the synthetic element Mendelevium (atomic number 101) was named for him.

IMPACT

Mendeleyev charted the positions of the elements in what became known as the periodic table of elements, and researchers of the late nineteenth century expanded the principles of chemical knowledge enormously because they had a logical foundation upon which to build their ideas. Before Mendeleyev's periodic table, chemistry as a science was in a fair amount of chaos. Although new elements were being discovered, there was little, if any, consistency in the use of symbols and abbreviations, and no one could work out how to organize the elements in a sensible way. Mendeleyev listed elements according to their known atomic weights and recognized repeating patterns in their behavior. He wisely left gaps in his table, anticipating that they would be filled by future discoveries, and indeed the "missing" elements were discovered. He also predicted the discovery of new elements with extraordinary accuracy, and he set other chemists on the trail for other hidden elements.

By the beginning of the twentieth century, chemistry was progressing as rapidly as physics, and links between them were becoming better understood, so that chemistry could successfully underpin physics, providing a symbiosis that led to faster advances in science. Chemical knowledge and biological insights also began to fuse, giving the world both organic chemistry and biochemistry, whose combination has created some of the most profound developments in both pure and theoretical science. Today, no chemistry classroom or chemical laboratory is complete without a periodic table of elements.

—*Tel Asiado*

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See also: Robert Wilhelm Bunsen; Joseph-Louis Gay-Lussac; Glenn Theodore Seaborg.

GERARDUS MERCATOR
Flemish cartographer

Mercator was a Flemish engraver, surveyor, scientific instrument maker, and mathematician best known for the map projection bearing his name. He is considered to be the first modern cartographer.

Born: March 5, 1512; Rupelmonde, Flanders (now in Belgium)
Died: December 2, 1594; Duisburg, Duchy of Cleve (now in Germany)
Also known as: Gerhard Kremer (birth name); Gerard de Kremer *or* Cremer
Primary fields: Cartography; geography
Primary invention: Mercator projection map

EARLY LIFE

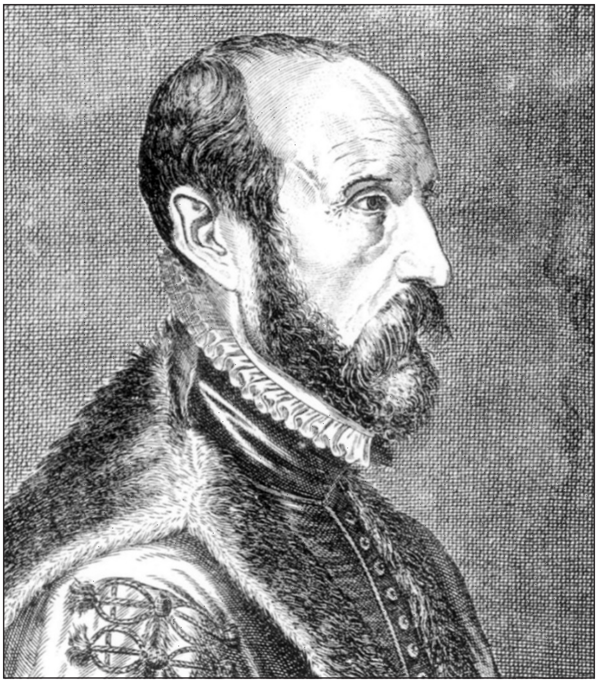
The son of a shoemaker, Gerardus Mercator (gehr-AHR-duhs mur-CAY-tur) was born Gerard Kremer in Rupelmonde, Flanders, near the present-day city of Antwerp, Belgium. His family was not wealthy, so an uncle provided financial support for fifteen-year-old Gerardus to attend Shertogenbosch, a monastic school in the Netherlands. While at Shertogenbosch, Gerardus learned Christian theology and Latin and developed skills in writing with italic script. In 1530, Gerardus enrolled at the University of Leuven (Louvain) to study philosophy and mathematics. Following a common practice among young scholars of the time, Gerardus changed his name from Kremer, meaning “peddler,” to the Latinized Mercator, meaning “merchant.” While attending the university, Mercator was captivated by lectures from Gemma Frisius (1508-1555), a Dutch astronomer and mathematician who became Mercator’s teacher and mentor. In addition to his academic pursuits, Mercator became interested in the design and construction of scientific instruments, including globes and surgical tools. Mercator was awarded a master’s degree in philosophy in 1532. At the age of twenty-four, he married Barbara Schellekens, who gave birth to the first of three boys and three girls the following year.

Although Mercator’s principal source of income came through the construction of instruments, he maintained a strong interest in mapmaking and engraving. In 1537, he published his first map, a 17-by-39-inch representation of Palestine on six panels intended to be used for illustrating Bible texts. The map was a commercial success, remaining in print for more than forty years. In 1538, Mercator created a world map based on a double cordiform, or heart-shaped, projection. This map was considered innovative at the time because it separated America into separate northern and southern hemispheres and depicted North America as physically separate from Asia.

LIFE’S WORK

Mercator’s fame expanded with the 1540 publication of his map of Flanders (*Exactissima Flandriae descriptio*) based on field surveys carried out between 1537 and 1540. The map was deemed to be extremely accurate for its time because Mercator used triangulation methods in the field. It was also during this period that Mercator’s skills in creating scientific instruments brought him in contact with navigators and cartographers from Portugal and Spain who were associated with the royal court of Holy Roman Emperor Charles V (1500-1558).

Mercator’s shift toward Protestantism and growing scholarly reputation made him a target for religious extremists and led to his arrest in 1544 for heresy. After seven months imprisoned in the Rupelmonde Citadel, he was released at the urging of friends, colleagues, and local officials. However, others detained during the same



Gerardus Mercator. (Library of Congress) period were held longer, including four who were executed. In 1552, Mercator moved his family to Duisburg on the Rhine River in Germany to assist in the organization of a new university. Although the university was never realized, Mercator received an appointment as cosmographer to Duke Wilhelm of Cleve (1516-1592).

At his workshop in Duisburg, Mercator remained busy fulfilling requests for maps, globes, and scientific instruments from both royal and private patrons. In 1554, he published a map of Europe in fifteen separate sheets using information from existing maps and field reports. Searching for more accurate geographical representations, Mercator demonstrated a willingness to abandon older theories established by ancient scholars such as Ptolemy. For example Mercator recognized that the Canary Islands were much further west of the Straits of Gibraltar than was accepted at the time. New measurements were incorporated into his European maps, such as a reduction in the length of the Mediterranean Sea by 10 degrees of longitude. In 1564, he printed a map of England, Scotland, and Ireland on eight panels that was considered to be extremely accurate. Although not revealed on Mercator's maps, fieldwork for this map is believed to have been carried out by John Elder, a Scotsman who traveled throughout England and Europe. Cartographic historians believe Elder copied information from secret maps maintained at the British Royal Library.

The Mercator Projection

Late Renaissance exploration of the world, especially the Americas, brought an increased demand for maps to support navigation at sea. A long-standing problem for seafarers was difficulty holding a line of constant compass bearing, or loxodrome, resulting in navigation errors of hundreds of miles. Flemish cartographer and mathematician Gerardus Mercator is credited with developing the first projection capable of maintaining loxodromes as straight lines. The term "projection" refers to a mathematical system for transferring information from the spherical shape of Earth to a flat surface. Mercator's cylindrical projection featured parallels (lines of latitude) and meridians (lines of longitude) crossing at right angles. Whereas meridians on the spherical Earth converge at the poles, they remain equidistant on the Mercator projection. Likewise, instead of growing progressively shorter with increases in latitude, the lengths of parallels on the Mercator projection remain constant. The resulting map has parallels that are close together near the equator and more widely spaced in higher latitudes.

Despite its advantages, the projection was not used immediately for navigation because Mercator did not release the mathematical formula used in its construction. Others, such as Antwerp mathematician Michiel Coignet (1549-1623) attempted to solve the problem by calculating the length of a loxodrome in small sections. In 1599, mathematical astronomer Edward Wright (1561-1615) published "Certaine Errors in Navigation," which presented the basic mathematical foundation for the projection.

An unfortunate attribute of the Mercator projection is severe distortion to the sizes of areas in high latitudes when compared to regions in the tropics. For example, Mercator's map shows Greenland (840,003 square miles) as larger than Africa (6,870,687 square miles). Because of the increasing space between parallels, world maps based on the Mercator projection must be drawn with high-latitude areas omitted, meaning that Greenland and Antarctica are cut off. Although well-suited to navigation, the popularity of the Mercator projection resulted in inappropriate or poorly conceived applications such as political maps and wall-sized world maps. An equal-area cylindrical projection introduced by Arno Peters (1916-2002) in 1973 attempted to "correct" misconceptions in the relative size of areas that had been promoted by widespread use of the Mercator projection.

Mercator's most significant contribution was the map projection bearing his name. A long-standing difficulty in ocean navigation during the 1500's was a discrepancy between compass readings and directions shown on charts, causing seafarers to miss their destinations by hundreds of miles. Created in 1569, the Mercator projection addressed this issue by representing the compass bearing between any two points as a straight line. Maps based on the projection were characterized by parallels and meridians that crossed at right angles. Although useful for navigation, the increasing distance between parallels extending from the equator to each pole resulted in distortions to the sizes of terrestrial regions, especially in higher latitudes.

In addition to compiling and engraving flat maps, Mercator also contributed procedures for the construction of globes. Mercator constructed his first globe in 1537 for his mentor, Frisius. In lieu of time-consuming methods for creating globes by engraving directly to a spherically shaped wood or brass form, Mercator developed a method in which papier-mâché was applied over a wood mold for each hemisphere. The two halves were then joined and covered with a mixture of thin plaster. Subsequently, Mercator would apply a set of flat maps, called gores, with edges that narrowed near the poles. In 1541, he created a navigator's globe intended for use at sea that measured 16.5 inches in diameter. This was followed in 1551 with a celestial globe.

Mercator dedicated his later years to a project for joining revised versions of Ptolemy's maps with a collection of modern maps he called "Atlas," in honor of the legendary philosopher, scientist, and king of Libya credited with constructing the first terrestrial globe. Published in 1578, the first volume of Atlas included twenty-seven of Ptolemy's maps restored and supplemented with an index of place names. In 1585, Mercator published another volume that included modern maps of Germany, France, and the Netherlands, with a third volume appearing in 1589 that contained additional maps showing the Balkans and Greece. Mercator died in 1594 and was buried inside St. Savior's Church in Duisburg. At the time of his death, he had outlived five of his children. A year after his death, the final volume of his atlas was published by his youngest son. "Atlas sive cosmographicae meditiones de fabrica mundi et fabricati figura" ("Atlas, or Cosmographic Meditations on the Fabric of the World and the Figure of the Fabrick'd") included 107 maps, most representing southern and western Europe. Many of Mercator's original engravings were sold to Dutch cartographer Jodocus Hondius (1563-1612), who continued publishing the maps for many years. Hondius and his sons also published smaller and simplified versions of Mercator's original atlas in several editions, including French, German, and English language translations.

IMPACT

Mercator's cartographic methods challenged conventional thinking. In addition to producing some of the most accurate maps of his day, he was the first to divide the continent of America into two parts, *Americae pars septentrionalis* (the northern part of America) and *Americae pars meridionalis* (the southern part of America). Mercator is also credited with being the first to use the word "atlas" to describe a book that contained a collection of maps. Mercator is best known for developing the projection named for him that improved the usefulness of charts employed in sea navigation. Maps based on the Mercator projection were used for centuries after Mercator's death by explorers, including Captain James Cook (1728-1779). More recently, Mercator's map projection has fueled controversy among geographers, historians, and others because of its use in creating misleading maps.

Mercator was remarkable among cartographers of his day. Unlike some of his contemporaries, he personally constructed and engraved the majority of maps in his publications. His maps were innovative, accurate, and aesthetically attractive. In addition to his contributions to mapmaking, engraving, and the construction of scientific instruments, Mercator published books on topics ranging from science and mathematics to ancient geography. His versatility as a scholar is further demonstrated by his studies of terrestrial magnetism.

—*Thomas A. Wikle*

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See also: R. Buckminster Fuller; Ptolemy.

OTTMAR MERGENTHALER

German American mechanical engineer

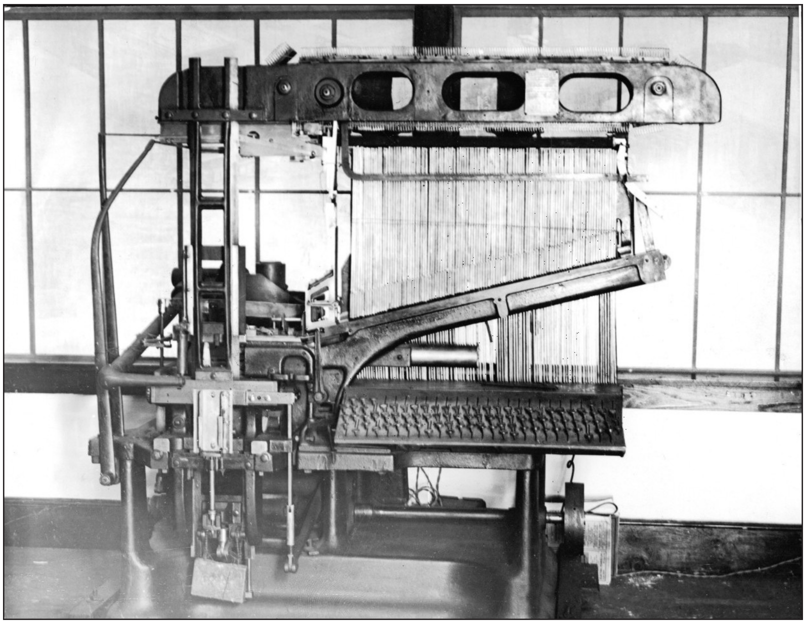
Often called the "second Gutenberg" because of his contributions to the advancement of movable type, Mergenthaler invented a machine that could set type quickly and accurately at the touch of a key.

Born: May 11, 1854; Hachtel, Württemberg (now in Germany)
Died: October 28, 1899; Baltimore, Maryland
Primary field: Printing
Primary invention: Linotype machine

EARLY LIFE

Ottmar Mergenthaler (OT-mahr MUR-guhn-thaw-lur) was born in the town of Hachtel in the valley of the Tauber River in Württemberg (now in Germany). Soon after Ottmar's birth, his father, a schoolteacher, moved to Ensingen, where little Ottmar would prove a mechanical prodigy. As a boy at his stepmother's side, he created for her a dough press to make *Springerle*, his favorite Christmas cookie. The town square in the Mergenthalers' new hometown was dominated by a large and beautiful clock, which, however, had not run for years. None of the clockmakers in the region could get it to work. One evening in 1868, however, the people of Ensingen heard the melodic chimes of evensong, and they soon realized that the schoolteacher's thirteen-year-old son had accomplished what the master clockmakers had not been able to do.

When young Ottmar begged to be a watchmaker, his father apprenticed him to a stepuncle named Louis Hahl in Bietigheim. When he heard glowing stories about life in America, however, where Hahl's son August owned a machine shop, the journeyman Mergenthaler wanted to move there. In 1872, when Ottmar turned eighteen, the younger Hahl paid his passage to Baltimore. Mergenthaler made knives and tools, and in two years he had his first patent.



The world's first Linotype machine. Ottmar Mergenthaler's invention revolutionized printing, especially the newspaper publishing industry, with faster, more efficient typesetting. (Getty Images)

LIFE'S WORK

On the strength of his inventive genius, Mergenthaler was made a partner in August Hahl's machine shop in 1875. They specialized in building models for other inventors. About ayear later, a man named Charles Moore came to the firm of Hahl and Mergenthaler for help with an invention of his that, like the Ensingen clock, simply did not work. Moore, a printer, wanted to be able to set type mechanically, eliminating the inefficiency of hand-setting. Mergenthaler immediately saw major flaws in Moore's design, and he set about redesigning the "transferable typewriter" (as Moore called it) from scratch.

The Linotype Machine

Ottmar Mergenthaler's Linotype machine was the first true innovation in typesetting since Johann Gutenberg had introduced movable type to Europe four centuries earlier. The beauty of the machine is the complexity of the design (with more than five thousand parts in the initial design; by 1892, Mergenthaler had reduced that to thirty-five hundred), combined with the simplicity of operation. The Linotype operator simply types at a keyboard of ninety characters. Like the typewriter keyboard, the Linotype does not use alphabetical order: the characters are arranged according to frequency, from most common (on the left) to least-used (on the right). No shift key is necessary: capital and lowercase letters have separate keys, capitals in white on the left, lowercase in black on the right, and numbers and other characters in blue in the middle.

Striking a key releases a brass mold (matrix) from a magazine, a vertical box divided into ninety columns (channels), each containing a different character. Each matrix has a letter or other figure engraved on it; this becomes the mold for the line of type. For type smaller than twenty-four points, each matrix has two forms of the letter or character, roman on the bottom and italic on the top. To switch to italic, the operator pushes in a rail that raises the matrix, causing the italic form of the letter to be impressed. Each letter is deposited onto a frame called the assembler, side by side in sequence as it is typed. When a space is needed, the operator touches a space-band lever to the left of the keyboard, and a blank matrix (space band) is added. The space band is wedge-shaped so that it can expand to make the space between words wider or narrower as needed to justify (line up left and right) the line.

As soon as a line of type is completed, a reservoir of hot metal (550° Fahrenheit, or 288° Celsius) empties into the matrices, forming a line of metal type called a slug. The molten metal is then water-cooled so that the slug hardens immediately. It then passes to a knife block assembly that trims any excess metal, and the slug is ejected. The matrices are immediately returned to the magazine, so that the process can never exhaust even the most common letter—the lowercase *e*. That letter actually takes up two channels (the first two on the left) so that, while the keyboard has ninety keys, the magazine actually has ninety-one channels. The returning matrices are sorted in the distributor. Each matrix has a unique pattern of teeth, like the wards on a lock and key. As soon as a returning matrix reaches the channel in which it belongs, the cut-away teeth of the distributor bar match the teeth of the matrix, and it falls into the proper channel. The beauty of Mergenthaler's design is that, once each line has been typed, the remaining process is automatic.

One aspect of Moore's design captured Mergenthaler's imagination. Instead of placing type directly into a frame for printing, Moore envisioned a brass mold into which molten lead would be poured to make a whole line of type at a time. Moore's description of the mold process sounded precisely like the dough press Mergenthaler had made for his stepmother's cookies. The mold, however, was only one part of the process. In fact, the machine Moore had wanted was really two machines: The process required selecting individual letters from a case of type, framing them a line at a time, pressing them into a mold, pouring molten lead, allowing it to harden, and depositing the line of type in one lead slug, to be placed on the press. So many operations were needed that it took Mergenthaler more than a decade to work out all the bugs.

Each year brought a major setback. Early in the process, a fire in Mergenthaler's shop destroyed all of his plans and models. He was tempted to give up the project, but the thought that his father the schoolteacher had wanted him to be an educator too, and that his invention could drastically reduce the cost of books, made him persevere. In addition, one of the neighboring firms on Mercer Street in Baltimore was that of printer Louis C. Schneidereith, a fellow German American who was professionally interested in Mergenthaler's invention, and he encouraged the inventor not to give up. Another early supporter was Whitelaw Reid, editor of the New York *Herald Tribune*, who wanted his paper to get in on the ground floor of this new technology.

At each step of the development of the Linotype machine, Mergenthaler broke new ground in solving mechanical problems. With each solution, he filed a new patent; more than fifty patents were involved in Mergenthaler's first machine. A major breakthrough was simply thinking of it as a single machine rather than a series of devices, as Moore had envisioned. One day while riding the train, the obvious occurred to Mergenthaler: Unite the processes of casting and stamping in the same machine. Finally, in 1886, Mergenthaler filed his final Linotype patent—for the completed machine, patent number 317,828. On July 3 of that year, Mergenthaler demonstrated the Linotype to the *Herald Tribune*'s compositors, and the paper began converting to machine typesetting immediately. To show that the new technology was not limited to newspapers, Mergenthaler and the

Herald Tribune published *The Tribune Book of Open-Air Sports* the following year (1887).

The compositors had mixed feelings about Mergenthaler's machine. On one hand, their union had been pressing the *Herald Tribune* for a nine-hour workday; with the paper's numerous editions, most typesetters had been working twelve or more. The Linotype made the shorter workday possible. Unfortunately, it also led to the loss of many typesetting jobs. Union trouble and complaints of shareholders delayed the implementation of this revolutionary technology. Other newspapers, partly out of rivalry with the *Herald Tribune*, opposed the new machine in editorials. The German press was particularly vicious.

Mergenthaler lived long enough to see his invention triumph, however, and become, by the late 1890's, the standard means of setting type for American newspapers. A decade after his initial demonstration, when Mergenthaler returned to visit his hometown in Germany, the full impact of his invention was finally acknowledged both there and abroad, and he was hailed as a hometown hero. Upon his return to Baltimore, however, Mergenthaler, worn out from the trip, sought medical attention and discovered that he had contracted tuberculosis. Mergenthaler was only forty-five years old when he died in 1899.

IMPACT

For nearly a century, before the advent of computer typesetting in the 1970's, Mergenthaler's Linotype was virtually the only way text was printed for large press runs in the United States and Europe. The printing industry called the machine "Linotype," but well into the 1970's journalists still called the Linotype machine a "Mergenthaler." Before the summer of 1886, not a single U.S. newspaper had more than eight pages—not even in press-hungry New York City, with its dozens of dailies. A skilled union typesetter could set a line per minute for a pre-Linotype newspaper. With Mergenthaler's machine, the rawest apprentice could set four per minute; with practice, up to seven. Since that labor constituted the major cost of printing a newspaper, Mergenthaler had effected a fourfold reduction in cost. The hefty Sunday paper of one-hundred-plus pages in several sections was now feasible—and it soon appeared. Mergenthaler's influence is also remembered in two legacies in the Baltimore area: The city's major vocational school is named after him (Mergenthaler Vocational High School, known to locals as MERVO), and, on the collegiate level, one of the academic buildings at The Johns Hopkins University is Mergenthaler Hall. Other great inventors of his time—an era rich in inventors—admired his accomplishment. Thomas Alva Edison called Mergenthaler's Linotype the eighth wonder of the world.

—John R. Holmes

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Romano, Frank J. *Machine Writing and Typesetting: The Story of Sholes and Mergenthaler and the Invention of the Typewriter and the Linotype*. Salem, N.H.: GAMA, 1986. Linking Mergenthaler's Linotype with the concurrent invention of the typewriter by Christopher Latham Sholes supplies a larger context of the development of print technology at the end of the nineteenth century.

See also: William Bullock; Johann Gutenberg; Mark Twain.

GEORGES DE MESTRAL

Swiss engineer

Mestral revolutionized the fastening industry with his invention of Velcro. The multiuse product totally changed the concept of fastening and made it easy, quick, and adaptable.

Born: June 19, 1907; Colombier, Switzerland
Died: February 8, 1990; Commugny, Switzerland
Primary fields: Household products; manufacturing
Primary invention: Velcro

EARLY LIFE

Georges de Mestral (zhohrzh deh meh-STRAHL) was born at Château de Saint-Saphorin-sur-Morges in Colombier, Switzerland, on June 19, 1907. He was the son of Albert de Mestral, an agricultural engineer, and Marthe de Goumoëns. From an early age, Mestral was interested in technology. When he was twelve years old, he designed a toy airplane for which he obtained a patent. He studied at the École Polytechnique Fédérale de Lausanne and graduated in 1930. He then worked in the machine shop of an engineering company. In 1932, he married Jeanne Schnyder; he remarried in 1949, to Monique Panchaud de Bottens; and his third marriage was to Helen Mary Dale. He had two sons, Henri and François.

Mestral enjoyed participating in outdoor activities and was an amateur mountaineer and a hunter. He often took long walks accompanied by his dog. In 1941, while hunting in the Alps near Geneva, he noticed how burdock burrs stuck to his dog's coat and to the wool pants he was wearing. Mestral was fascinated by this phenomenon and began to study the burrs under a microscope. He discovered that the burrs had small hooks that fastened themselves into the fibers of his trousers and also became entangled in his dog's fur. Mestral believed that this configuration of hook and loop could be used to fasten two items together if he could discover a way to make the hooks and loops.

LIFE'S WORK

After his discovery of the hook-and-loop concept in 1941, Mestral spent the next eight years searching for the right materials to use to create a fastening system. During most of this time, Mestral met with little encouragement. Most people gave little credence to the practicality of creating fasteners based on the sticking power of burrs. Mestral eventually found a weaver in Lyon, France, who had enough faith in Mestral's idea that he made two cotton strips based on Mestral's theory. The strips worked but were quickly worn out.

Mestral then decided to try various synthetic materials. He discovered that nylon, which was only recently invented, was the best material to use for his fasteners, and he quickly succeeded in making the loops for the fasteners. Creating hooks that would match up and secure into the loops remained a problem. He finally solved his dilemma by making loops and then cutting the loops to

A Velcro hook-and-loop fastener. (Time & Life Pictures/Getty Images)

VELCRO

Georges de Mestral's invention of Velcro, a hook-and-loop fastening product, was the result of his keen observation, curiosity, and creativity. After returning home from a hunting trip with his dog, Mestral noticed that his wool trousers were covered with burrs and his dog's fur was matted from them. Inspired to investigate why this was so, Mestral examined a burr under his microscope, discovering that the burr was made up of thousands of stemlike pieces with hooks on the ends. He determined that these very small hooks were capable of attaching to any fabric or item that could be penetrated by the hooks (his trousers) or in which the hooks could become entangled (his dog's fur).

Mestral was convinced that this hook-and-loop concept, which was similar in a general way to the hook and eye already in use, could be used to create a new and superior fastener with great versatility. He conceived of a fastener that would be two strips, one with hooks and the other with loops. Finding the right material, creating the hooks and loops, and developing machinery to make the product became a ten-year-long research project.

Mestral's first hook-and-loop fasteners were made of cotton. They held together but lacked durability and had to be replaced frequently. Mestral next investigated synthetic materials, and he found nylon to be his best choice. Nylon possessed the qualities necessary for making a durable fastener; in addition, when it was produced, the thickness of the threads composing it could be varied. Mestral also discovered that when nylon was sewn under infrared light, it formed the type of hooks that he needed. The loops presented a greater challenge, but he persisted and discovered that nylon sewn in loops and heat-treated made the right loops for his hooks. One problem remained: The loops had to be cut properly to match up to the hooks. To solve this problem, Mestral changed the way he made the hooks. He sewed loops and then cut them; this made the hooks that mated to the loops.

Although Velcro was at first viewed as "funny looking" and was not readily accepted, Mestral soon saw his invention become the way to fasten a wide variety of items, from space suits to children's clothing. It also became a popular attachment fabric in a broad range of important scientific areas as well as in everyday uses. Its contribution to the aerospace industry has been invaluable because of its lightness, durability, and adaptability. Velcro has also enhanced the success of heart surgery procedures.

make the hooks. Next, he had to develop a method for mechanizing the process and finally a loom that not only wove the loops but also cut them properly to make the hooks. Finally, in 1948, he had solved the technical problems and was able to make his fasteners based on the sticking action of burrs. At first, Mestral called his invention "locking tape," but he later combined the first syllables of the French words *velours* (velvet) and *crochet* (hook) to name his invention "Velcro." In 1951, he applied for a Swiss patent, which he received in 1955. In 1952, Mestral started his first Velcro manufacturing company, located in Switzerland, with the support of Gonet and Company.

Mestral quickly obtained patents and opened factories in other countries, including Germany, Great Britain, Italy, Sweden, Belgium, and Canada. In 1957, he obtained a patent in the United States and opened a factory in Manchester, New Hampshire. When he introduced Velcro in these countries, Mestral thought his invention would have immediate and widespread success, but Velcro was very different from anything that had been used in the clothing industry. Although Velcro was actually a miniature version of the traditional hook and eye, the minute size of the hooks and loops gave the impression of an old fuzzy piece of cloth. Furthermore, people were not convinced of Velcro's practicality.

In spite of this initial hesitancy to accept Velcro, Mestral's invention began to conquer one market at a time until it became one of the most successful and widely used commercial products. Mestral enjoyed his first real success with Velcro when it was used to assist astronauts to get in and out of their space suits. Skiers were the next group to see the advantages of Velcro, followed by the makers of scuba gear. Then, led by the manufacturers of children's apparel, the clothing industry began to use it. Mestral's invention became so popular that his company earned millions of dollars.

Mestral insisted that Velcro was the name of his company and that what he produced was a hook-and-loop fastener. He waged a constant battle against the use of the term "Velcro" to identify all hook-and-loop fasteners that resembled his. Mestral eventually sold his company and all of the patent rights. Velcro was not Mestral's only invention. He also invented a hygrometer and an asparagus peeler, which was a very successful commercial product.

In 1966, upon the death of his father, he inherited the family château. He died at the age of eighty-two on February 8, 1990, in Commugny, Switzerland. L'avenue George de Mestral in Commugny is named in his honor.

He was inducted into the National Inventors Hall of Fame in 1999.

IMPACT

Mestral completely changed the concept of fastening with his invention. He invented a system of attaching one item to another and of fastening two parts of a single item by a means that was not only secure but also exceptionally easy to fasten and unfasten. The hook-and-loop fastener, Velcro, contributed in a significant way to the development of aerospace technology, as the lightweight Velcro provided a simple way to attach items in space. Mestral's easy-to-use invention has given a greater degree of independence to the disabled and the elderly. It also serves as a valuable means of attachment in many fields of surgery, especially heart procedures.

Velcro has become a part of everyday life. It fastens clothing, shoes, lunch boxes, and backpacks, and it holds draperies and car speakers in place. Although Mestral waged a persistent battle against the word "Velcro" replacing "hook-and-loop fastener," he had simply named his invention too well. "Velcro" has become not only the generic noun used for the hook-and-loop fastener but also a verb. Velcro has become a part of popular culture: It has been referenced in films and used in stunts on television shows such as the *Late Show with David Letterman*. Velcro has become as widespread and as much a part of life as the burrs to which it owes its invention.

—*Shawncey Webb*

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See also: Wallace Hume Carothers; Jerome H. Lemelson.

ROBERT METCALFE

American electrical engineer and computer scientist

In the early 1970's, Metcalfe became the coinventor (with his colleague David Boggs) of Ethernet, a system allowing instantaneous communication between computer terminals in a local area network. Like the Internet and the World Wide Web, the Ethernet would become essential to communication technology in all areas of the globe.

Born: April 7, 1946; Brooklyn, New York
Also known as: Robert Melancton Metcalfe (full name)
Primary fields: Communications; computer science
Primary invention: The Ethernet

EARLY LIFE

Born in Brooklyn, New York, in 1946, Robert Melancton Metcalfe graduated from Bay Shore High School in Suffolk County on Long Island in 1964. His undergraduate schooling at the Massachusetts Institute of Technology (MIT) led to two degrees in 1969: He earned a B.S. in electrical engineering and a degree in management from MIT's Sloan School of Management. Although it was not immediately apparent, this business-related training (especially where entrepreneurship was concerned) would play an important role in later stages of his career.

After receiving his M.S. in applied mathematics from Harvard in 1970, Metcalfe continued in the doctoral program there, but he continued to cooperate actively with MIT's Project MAC, a program that aimed at linking all the university's computers to the Advanced Research Projects Agency Network (ARPANET). ARPANET was the newly emerging U.S. Department of Defense project that sought to develop "packet-switching" technology in data communication as an improvement over "circuit-switching" methods employed in standard telephonic communication.

LIFE'S WORK

After failing his Ph.D. at Harvard in 1972 (his dissertation topic focused on ARPANET), Metcalfe received his degree in 1973. His ultimately successful research combined his interest in ARPANET with analysis of problems and possible solutions in another system emerging at the time at the University of Hawaii, appropriately named ALOHANET. The technology of both systems and the challenge of overcoming some of their shortcomings (in ALOHANET's case, problems of "collisions" in a system relying on radio waves rather than telephone wires for intrasystem data transmission) would serve as a stepping-stone to Metcalfe's work on the ultimately much more successful Ethernet.

Metcalfe coinvented Ethernet during the first year of his employment at Xerox's Palo Alto Research Center (PARC) in California, in November of 1973. He and colleague David Boggs designed Ethernet to connect the Xerox computers to one another through a local area network (LAN). Although Xerox at this time was concentrating most of its efforts on development of early models of the personal computer (PC), Metcalfe wanted to pursue research related to LANs. While he continued to concentrate on this technology, he accomplished another important assignment at Xerox—helping to develop the Xerox Star workstation, one of the first commercial PCs with a graphical user interface. Other features of the PC included file servers and the new star of the computer world, the mouse.

Six years after his pioneer work at Xerox, and after working out some of the early technical difficulties associated with Ethernet, Metcalfe resigned from PARC to found 3Com, headquartered in Santa Clara, California. 3Com manufactured computer networking equipment, with concentration on Ethernet technology. The firm's name symbolized the integration of three main "coms"—

ETHERNET

Although a full understanding of the Ethernet system demands a sophisticated knowledge of electronic technology, a layperson's understanding can be built on a few essential principles. As a system connecting a transmitting vehicle (in this case, a computer) to a network of receivers, Ethernet shares some characteristics with cable television. The first generation of Ethernet made it possible to transmit "packets" of computer-generated data back and forth along a passive electronic bus (a bus wire with at least two signal transmission wires "tapped" by a number of interconnected circuits, or transceivers) constructed in such a way as to form an annular unit, or "ring." Each Ethernet station, or computer terminal, in the local area network (LAN) is assigned its own 48-bit MAC address, marking both a potential source point and a destination point for any data packets transmitted through the system. In order to control "traffic" and "collisions" (disruptions of transmission that can be compared with radio wave interference) within the intercommunication ring, each Ethernet station is equipped with a computer chip called a network interface card. This device can distinguish between data that is general for the LAN as a whole and more specifically addressed transmissions.

Early Ethernet bus technology used coaxial cables similar to cable television systems. Basic coaxial cables had a limited transmission capacity (expressed in megabits per second, or Mbps). As developing technology discovered ways to build systems that had higher transmission capacity and decreased incidents of collisions when multiple senders and receivers of data "competed" within the LAN loop, Ethernet models progressed from the 10BASE5 (10-Mbps capacity) to the 100BASE-T (100-Mbps capacity, using an improved "twisted-pair" connecting cable) to several succeeding generations of Gigabit Ethernet (transmitting multiples of thousands of megabits per second). Twisted-pair Ethernet technology had the effect of reducing the physical panel space required for setting up a LAN. Also, with time, companies that specialized in network interface card production were able to incorporate Ethernet chips into the electronic package of almost all personal computers, thus contributing to decreasing costs of ever more sophisticated computer systems available on the market.

Along with improving transmission capacity, researchers succeeded in developing technology that would allow both longer "reach" and decreased malfunction vulnerability in LAN networks. In the latter case, a variety of system configurations were devised to achieve higher efficiency compared to stations arranged in a single line. Another, more complicated, feature of evolving Ethernet technology involved development of packet switching to overcome the limitations of circuit switching—a carryover from basic telephone wire technology. Circuit switching involves a dedicated (single and uninterrupted) "busy" signal, whereas packet switching occurs when transmitted data are broken down and assembled into "data graphs" that can be sent simultaneously in a packet, components of which can be distributed to various destinations within the LAN.

computers, communication, and (technological) compatibility. Over several years' time, Metcalfe's company worked, apparently quite successfully, to establish cooperative links between companies such as Intel, Digital Equipment Corporation, and Xerox, which were destined to play major roles in marketing Ethernet technology. By the 1980's, these three companies had joined to form a consortium to develop the 10BASE-T Ethernet standard, which operated at 10 megabits per second (Mbps). This initially impressive accomplishment was followed in the 1990's by the development of three distinct "successor" systems that increased the speed of Ethernet transmission by a factor of ten: the 100BASE-TX and the 100BASE-T4 (1995), and the 100BASE-T2 (1997). Among other highly technical improvements in these and later, even faster versions would be the adoption of different forms of cabling.

In 1990, Metcalfe left 3Com to begin a markedly different stage of his career. Between 1990 and 2001, he was engaged in technology-related publishing and also contributed an Internet column for the internationally known Web site InfoWorld. In the same period, he served as a principal founder of Pop!Tech, a widely recognized conference held yearly in Camden, Maine. Pop!Tech meetings focus on issues of popular culture and the Internet as well as ethical questions relating to Internet technology. Readers of the volume *Beyond Calculation: The Next Fifty Years of Computing* (1997), edited by Metcalfe and his professional associate Peter Denning, can see the diversity of such issues as the new century approached.

By 2001, Metcalfe had entered the arena of venture capitalism, participating as a general partner in Polaris Venture Partners, a company that, since its founding in 1996, has invested seed money in a variety of emerging companies ranging from health care technology companies to financial service companies. Metcalfe has received a number of awards recognizing his contribution to Ethernet technology. Early evidence of his success came in 1980 (just a year after he left PARC), when he received the Grace Murray Hopper Award from the Association for Computing Machinery. By 1996, six years after he resigned from the leadership of 3Com, the Institute of Electrical and Electronics Engineers (IEEE), the most important international professional association for electrical and electronic engineers, presented Metcalfe with the IEEE Medal of Honor. This award was not only for his coinvention of Ethernet but also for the leadership role he continued to play in its development and marketing around the globe. In addition to receiving the National Medal of Technology, awarded by President George W. Bush at a 2003 White House ceremony, Metcalfe was one of seventeen people named in 2007 to the National Inventors Hall of Fame.

IMPACT

After its introduction in the mid-1970's, Ethernet computer technology first competed with and then came to replace other systems designed to service LANs. Competitors included Token Ring, FDDI, and ARCNET. This success in gaining increasingly important sections of the market guaranteed that 3Com would become a model for a number of other start-up companies engaged in computer technology and the manufacture of computer components. Commercialization of Ethernet grew by the first years of the twenty-first century to handle about 85 percent of LAN-connected personal computers in all areas of the world. One of the main reasons for this success was cost-effectiveness: Installation procedures continued to prove more economical than those of other products on the market. Thus, from a relatively limited sphere of application in largely self-contained academic or business operations, the Ethernet was destined to become an affordable necessity in many different arenas where electronic communication has become a given in the modern world.

—Byron Cannon

FURTHER READING

Clark, David. "The Internet of Tomorrow." *Science* 285, no. 5426 (July 16, 1999): 353. A brief overview of the prospects for combining computer technology, including Ethernet, to create significant new horizons for research, business, and personal-use facilities.

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Denning, Peter J., and Robert M. Metcalfe, eds. *Beyond Calculation: The Next Fifty Years of Computing*. New York: Copernicus, 1997. Contains a variety of visions, both technological and objective as well as speculative and subjective, of changes in the world that were already occurring by the late 1990's as a result of computers. Contains a useful glossary of technical terms.

Metcalfe, Robert M. *Internet Collapses and Other InfoWorld Punditry*. Foster City, Calif.: IDG Books, 2000. Metcalfe's personal style in dealing with highly technical computer science issues (reflected in many of his contributions to the Internet Web site InfoWorld) can be seen in this work. One controversial subject, which earned Metcalfe a public image, involved predictions of Internet difficulties at the turn of the new millennium.

Von Burg, Urs. *The Triumph of the Ethernet: Technological Communities and the Battle for the LAN Standard*. Stanford, Calif.: Stanford University Press, 2001. An overview of the stages and successes of Ethernet technology.

See also: Tim Berners-Lee; Vinton Gray Cerf; Bob Kahn.

ANDRÉ AND ÉDOUARD MICHELIN

French industrialists and engineers

The Michelin Tire Company, founded by brothers André and Édouard, is recognized as a pioneer manufacturer of air-inflated tires. Although in later years the highly competitive tire industry witnessed many innovations offered by different companies at a wide range of prices, Michelin continued to enjoy a strong reputation for high-quality products.

ANDRÉ MICHELIN

Born: January 16, 1853; Paris, France
Died: April 4, 1931; Paris, France
Also known as: André Jules Michelin (full name)

ÉDOUARD MICHELIN

Born: June 23, 1859; Clermont-Ferrand, France
Died: August 25, 1940; Orcines, Puy-de-Dôme, France
Also known as: Édouard Étienne Michelin (full name)
Primary fields: Automotive technology; manufacturing
Primary invention: Rubber automobile tires

EARLY LIVES

In 1852, Jules Michelin (mee-shlan) married Adèle Barbier, daughter of the co-owner of Barbier, Daubrée and Company, an iron and copper foundry in Clermont-Ferrand, France. A year later, their son André Jules was born. André earned his diploma from the School of Arts and Manufacturing in Paris, and the directors of a troubled successor company to Barbier, Daubrée and Company, known as Jean-Gilbert Bideau and Company after 1868 (with the Barbiers still on the board), later called upon André to take part in the firm. In 1886, at the age of thirty-three, André, who had supplemented his training as an engineer with studies in the architectural branch of the Paris School of Fine Arts, accepted this job. He had already launched his own business in the Paris suburb of Bagnolet—a factory producing metal construction girders. André's life work after he took on responsibilities in Clermont-Ferrand would move in a different direction—the incorporation of rubber into different areas of industrial production.

While André seemed to be a logical choice to help rebuild the ailing foundry business, his younger brother Édouard Étienne was less likely to find a niche in manufacturing. Édouard had attended the same School of Fine Arts as André but chose studio painting as his preferred vocation. Only twenty-seven when he joined André, Édouard was destined to fill a very different, but major, complementary role (initially as managing director) of the firm that later bore his family name.

LIVES' WORK

The Michelin brothers made their first mark in the rubber tire industry in 1889, when they shifted company emphasis toward commercial use of vulcanized rubber: brake shoes with rubber linings. Just one year earlier, a much more important long-term breakthrough had been made in Belfast, Ireland, adopted home of the Scottish veterinarian John Boyd Dunlop, who took out a patent on the first air-filled rubber tire. Realizing how important this new product could be for work and passenger vehicles, the Michelins worked rapidly to improve on Dunlop's inflatable tires.

As the company entered into the market for tires, the brothers used a popular method of attracting attention: The superior performance of their tubular tire in the 1891 Paris-Brest-Paris (PBP) bicycle race and other nationally publicized events launched them on an advertising campaign. This campaign—as it moved into the emergent world of automobile travel—would make the name Michelin a widely recognized symbol, not only for tires but also (once the *Michelin Guide* was launched in 1900) for tourism in general.

The company's popular image grew with the adoption in 1898 of its mascot Bibendum (also known as the Michelin Man)—a rotund cartoon figure made of stacked tires with added human features. The figure's name comes from a Latin slogan originally used by a Munich brewery: *Nunc est bibendum* (now is the time to drink). Michelin would use Bibendum in different ways to draw attention to the company's activities—all commercially connected with the public's growing involvement in automobile tourism. Bibendum's amusing persona began to appear on the cover of and in advertisements in Michelin touring guides. These practical guides were distributed free until much-expanded editions (with details on hotels and restaurants) began to be published after 1920.

The growth of Michelin tire production in Clermont-Ferrand was very rapid. The number of Michelin employees rose from 62 in 1892 to 268 by 1894 (two years before the company introduced its first automobile tires) to 698 by 1898. Thanks to Édouard's skillful management and ever-improving methods of mass production, prices for Michelin tires were affordable for the average buyer. Shortly after the turn of the century, well over half of Paris's four thousand taxis were equipped with Michelin's product.

THE MICHELIN TIRE

The earliest versions of what came to be known as tubular tires (reinforced rubber tire casings with tread given durable but flexible shape by means of an air-filled inner tube) were introduced by the Scotsman John Boyd Dunlop in 1888. There was at least one precedent for the idea of air-filled tube tires. In 1845, Scotsman Robert William Thomson produced what he called "aerial wheels" for horse carts. Thomson's tires did not catch on, however, mainly because they were too expensive. Dunlop's model for bicycles and carts forty years later was more economically feasible, but because it (like Thomson's) was glued to the wheel rim, it was difficult to repair. Not only was the task of removal complicated, but regluing the patched tube to the rim also could not be finished "on the spot." The drying process could take hours.

André and Édouard Michelin began by devising an essentially mechanical system to rival Dunlop's. The answer, at least for the next few years, was still awkward: Michelin's method held the tube and tire to the wheel rim using more than thirty nuts and bolts. The next step, which would be adopted by all producers of tubular tires in the next generations, involved redesigning wheel rims so that the "lip" of the tire could be seated very snugly and grip all the way around the rim when inflated.

The Michelin company, however, would continue to make its mark through other technical improvements that went beyond mechanical devices. Important research and development projects aimed at producing higher-quality rubber components at lower prices. A major contributor to the firm's advances in this realm was the Alsatian chemist Maximilien Gerber. Perhaps the most challenging aspect of Gerber's work and that of his successors involved testing different types of tread surfaces not only for durability but also for traction depending on different road surfaces and weather conditions. A notable achievement here was what came to be known as the Michelin Universal Tread. Based on technical principles used in racing tires, even the Michelin Universal Tread seemed to incorporate publicity techniques that could be worked into the patent, as the tread consisted of closely knit rows of *M*'s.

The Michelin company was an innovative pioneer not only in terms of technology and publicity but also in methods of business management. Many historians focus on the company's attitude toward its workers who came to work in Clermont-Ferrand. Already by 1898, the company had launched a program that rewarded the best employees with business shares that could accumulate—if the recipients kept continuous employment with the company—until the age of retirement. In part, this apparent benevolence was connected with management's desire to avoid inroads by militant labor unions. Similarly, provisions for a variety of social services were always part of Édouard's managerial responsibilities. Starting in 1905, health services, for example, were included in employee benefits. By the interwar years, construction of inexpensive and practical company housing included apartment complexes and multiple- and single-family structures.

At a certain point, it became obvious that Michelin's competitive edge in European continental sales could be extended not only to Dunlop Tyre Company's "home territory" in Great Britain (where an extraordinarily ornate

Michelin building was built in London in 1911—replete with dual turrets representing the rotund Bibendum) but also to the United States. By 1910, acting on Édouard's managerial initiative, the company founded a factory in the small town of Milltown, New Jersey. In its heyday, the plant comprised twenty-two buildings and employed two thousand workers plus a number of French engineers and managers. In a U.S. version of what had guided Édouard's policy in Clermont-Ferrand, efforts were made to create a desirable "company town"—including standardized workers' housing and a number of community social organizations.

Around World War I, the Michelin brothers demonstrated interest in producing materials for use in the then-nascent aviation industry—first lightweight fabrics used to cover dirigibles, and then, once war broke out, metallic frames for what came to be known as the Breguet bomber. To protect the plane's landing gear from bullets, the Breguet biplane was equipped with steel wheels produced by Michelin. The company's involvement in the war effort went beyond production of war materials. Not only was its warehouse in Clermont-Ferrand converted into a military hospital, but a program also was introduced for pensions to surviving children of any company employees who died in the war.

Despite the company's dominance, Michelin was not unscathed by the Great Depression. The twenty-year-old plant in Milltown was forced to close down permanently, and in Clermont-Ferrand employment figures dropped from more than sixteen thousand workers in 1929 to half that figure by 1934. Somewhat unexpectedly, the downturn did not deter expansion in European-based operations during the height of the Depression: New plants were opened in Karlsruhe, Germany, in 1931 and in Lasarte in northern Spain in 1933. An even greater sign of the company's intention to weather the storm of depression came in 1935, when Édouard's son Pierre closed a deal with the then-ailing Citroën car company, which initially gave the Michelins a slight voting majority in Citroën even though their capital investment came to less than one quarter of the total. In the post-World War II period, Michelin actually owned Citroën, sharing responsibility for development of the first front-wheel-drive car.

André Michelin, who turned seventy-eight in January, 1931, did not live to witness these important developments. Soon after André died in March, 1931, his brother Édouard declared his intention to retire. His successor was to have been his thirty-three-year-old son Étienne, an amateur pilot who was killed in a plane accident. Édouard, apparently intent on passing the directorship on to one of his sons (thus sidestepping André's son Marcel, who had considerable practical experience in the firm), delayed his retirement so that his own younger son Pierre (who also died prematurely, in 1937) could take over. In his last years, therefore, worries over the future of the company faced the aged company's cofounder. First he was forced out of his intended retirement, then came the onset of the German occupation of France in June, 1940. Édouard died just two months after the Nazi invasion. He was thus spared the wrenching drama of forced service of the very valuable tire company under orders from the Third Reich.

IMPACT

The last two decades of the Michelin brothers' lives witnessed new developments that continued to expand their company's reputation in France and throughout the world in the twentieth century. One of these was production of tires for trucks. These were not only bigger and heavier tires; Michelin's products in the 1920's were especially designed for what was to become the dual wheel and later the quadruple rear wheel assemblies needed by exceptionally large trucks. In 1929, Michelin also took out a patent for the earliest air-filled tires for use in lightweight passenger trains—an innovation that gave its name to trains serving smaller cities throughout France (the Michelines). The first such train took its trial run in 1931 from Paris to the resort town of Deauville on the Normandy coast, setting a record time for passenger service on that line. Five years later, there would be ninety Michelines servicing regional routes in France. Another notable technological innovation would come just after World War II—development of the first radial tires—further enhancing the company's international reputation.

—*Byron Cannon*

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; John Boyd Dunlop; Henry Ford; Charles Goodyear; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; Ransom Eli Olds; Nikolaus August Otto; Stanford Ovshinsky; Sylvester Roper; Ignaz Schwinn; Felix Wankel; Alexander Winton.

JOHN MILNE

British engineer, geologist, and seismologist

Milne, regarded as the "father of modern seismology," invented the first modern seismograph. He also established the world's first international seismological monitoring network.

Born: December 30, 1850; Liverpool, England
Died: July 31, 1913; Shide, Isle of Wight, England
Primary field: Geology
Primary invention: Seismograph

EARLY LIFE

John Milne was born in 1850 in Liverpool, England, to John Milne and Emma Twycross. He grew up in the Greater Manchester towns of Rochdale and Tunshill, Milnrow. He received his early education in Rochdale and at Liverpool Collegiate Institute. Awarded a monetary prize for academic excellence when he was thirteen, he spent the money on a holiday tour of England's Lake District; from there, he decided to cross over to Ireland and continued to Dublin, subsisting largely on apples plucked along the way and whatever he could earn playing the piano at roadside pubs. An adventurer by nature, the adolescent Milne later took to exploring England's waterways by canoe.

At seventeen, he entered King's College, London, where he focused on geology and mechanics. After an expedition to Iceland, he continued his studies at England's Royal School of Mines, earning the credentials to become a mining engineer. He did fieldwork in practical mining engineering in Cornwall and Lancashire, studied mineralogy at the Bergakademie in Freiberg, Germany, and from there visited central Europe's principal mining districts.

After returning home, the twenty-two-year-old Milne was hired for a job overseas, where he spent two years assessing and reporting on the mineral resources of Newfoundland and Labrador. In 1874, he went back to England only to embark on yet another voyage, this time as part of British geographer Charles Tilstone Beke's expedition to Egypt to determine the location of the biblical Mount Sinai.

In 1875, Milne accepted a position in Japan as professor of mining and geology at Tokyo's recently established Imperial College of Engineering. Not fond of sea voyages, Milne made most of the trip over land. The months-long trek across Europe and Asia included one thirty-one-day stretch with no roads, no houses, no change of clothes, and little food. Upon reaching Japan in 1876, the seasoned adventurer had a new experience: On the night of his arrival in Tokyo, he felt his first earthquake.

LIFE'S WORK

Milne's appointment to the Imperial College was part of a Japanese program to hire foreign nationals to help the country gain parity with the industrialized West. During his first years there, Milne divided his time between his teaching duties and the various geological attractions his new home offered. He traversed the countryside and made scientific observations, excavated prehistoric shell mounds, and climbed and sketched volcanoes. He also experimented with instruments for monitoring earth motion during seismic activity.

On February 22, 1880, a moderately severe earthquake struck the Tokyo-Yokohama area. Milne was eager to study the quake and its effects, but locating its epicenter and assessing its relative strength and direction of movement proved to be a challenge. Had the quake struck an urban area in Europe, he would have determined its intensity through field observations of damage to structures. However, the commonly used intensity scales (developed in Italy) did not translate easily to Japan because Japanese architecture and construction techniques were so unlike the West's. Where Mediterranean

The Milne Seismograph

The Milne seismograph was a highly sensitive, horizontal-pendulum instrument. It consisted of a horizontal, lightweight aluminum boom with a weight at one end and a universal joint at the other end connecting it to a vertical iron column. Supporting the weighted end of the boom was a thin wire attached to the vertical column. The mass and position of the weight attached to the boom determined the pendulum's sensitivity and its period. Leveling screws in the base of the column allowed it to be tilted slightly, which reduced the gravitational restoring force and thus made it possible to get a long-period response out of the short-period pendulum.

When the earth shook, the vertical pillar moved with it, while inertia caused the heavy mass at the end of the boom to remain stationary in relation to the pillar. Photographic methods were used to create a visual record of the instrument's movements. Light from a lamp was reflected down through a horizontal slit on the weighted boom, passing from there through a fixed horizontal slit perpendicular to the boom's to form a spot of light on a roll of photosensitive paper beneath. The relative motion between the pendulum's slit and the fixed slit caused the spot on the paper to move. A clockwork mechanism rotated the roll slowly, so that it completed a revolution every few hours; the roll also underwent a slow horizontal advancement, allowing a day or two of readout to spool onto it.

Thanks to the worldwide deployment of the Milne seismograph, seismologists in the early twentieth century had access to an accumulated body of reliable, comparable teleseismic data. From these data, researchers began to construct a model of Earth's interior density, pressure, and elasticity, based on what the seismographic data revealed regarding how and how fast seismic waves traveled beneath the planet's surface. By 1906, John Milne had determined that Earth had a surface crust through which seismic waves traveled more slowly and a denser inner region through which they passed more quickly. Richard Oldham posited in 1906 that the planet had a large, dense, and probably fluid core. Andrija Mohorovičić discovered a discontinuity between Earth's crust and its mantle in 1909. In 1912, Beno Gutenberg calculated the depth to the outer boundary of the Earth's core. Almost a quarter of a century later, Inge Lehmann determined that the Earth has a solid inner core within a liquid outer core.

stone and masonry would collapse in a major quake, a wooden structure in Tokyo would sway and jerk violently only to return to its original state once the shaking stopped. To gather data, Milne had to turn to European expatriate communities in Tokyo where Western-style construction predominated. He also sent out questionnaires, surveyed fallen gravestones, and learned what he could from a scattered hodgepodge of seismic monitoring devices created by some of the Western scientists then living in Tokyo.

Milne and two fellow Englishmen also teaching at the Imperial College—Professor of Telegraphy Thomas Gray and Professor of Mechanical Engineering and Physics James Alfred Ewing—collaborated to found an organization that would pool the expertise of Japanese and foreign researchers to collect and systematize information about earthquakes in Japan. That organization, the Seismological Society of Japan, held its inaugural meeting two months after the Tokyo-Yokohama earthquake. With the support of the minister of public works, the society deployed a pendulum-type seismometer codesigned by Ewing, Gray, and Milne in several telegraph offices across the Musashi Plain, the area west of modern-day Tokyo. (The telegraph offices offered the combined conveniences of rapid communications and clocks that were synchronized daily.)

From 1880 on, Milne focused his attentions on earthquakes. He conducted research, wrote extensively (two-thirds of the articles the Seismological Society published were his), and designed monitoring instruments. He investigated small vibratory ground motions using microphones and studied his instruments' response to simulated earthquakes he created by dropping heavy iron weights and setting off gunpowder explosions. His classic *Earthquakes and Other Earth Movements* was published in 1886 and was reprinted numerous times over the next half century. In 1887, he was elected a fellow of the Royal Society, England's prestigious national academy of sciences.

Milne was in Japan during the great Nōbi earthquake of 1891, one of the largest seismic events in the country's history, and he conducted an extended field survey of the damage. When, in 1892, Japan's new Imperial Earthquake Investigation Committee superseded the Seismological Society, Milne began to devote more time to studying and recording teleseisms (distant earthquakes). In 1893, he created the Milne seismograph, a highly sensitive horizontal-pendulum instrument capable of detecting earthquakes occurring at a great distance.

In 1895, Milne's connection with the Japanese government came to an end. He returned to England—along with his wife, Tone Noritsune, and his assistant, Shinobu

Hirota—though not before a house fire destroyed many of his possessions, including instruments he had hoped to deploy in his home country. The Milnes settled on the Isle of Wight, in a location the seismologist chose based on the likelihood that small tremors could be felt there. At his new home, dubbed Shide Hill House, Milne set up a seismological laboratory and a seismograph station for detecting teleseisms and small local seismic events.

In 1897, Milne obtained funding from the Royal Society to establish an international network of earthquake monitoring stations equipped with Milne seismographs. Stations were established in roughly fifty locations, including sites in England and the British Empire, the United States, Canada, Russia, and Antarctica. The stations reported to Milne regularly, and he issued periodic catalogs of the world earthquakes the network detected. Milne used network data to create the first worldwide map of earthquake zones. He also published a second comprehensive text on earthquake science, *Seismology* (1898).

Shide Hill House became an international center for earthquake research. One visitor to Shide, a vacationing amateur scientist named John Johnson Shaw, wound up entering into a long-term collaboration with Milne to improve his eponymous seismograph.

In 1913, the year the Milne-Shaw seismograph was completed, Milne died suddenly from Bright's disease at the age of sixty-two. The seismological network headquartered at Shide continued for another six years before being transferred to Oxford University.

IMPACT

Milne played a major role in making seismology into a modern, quantitative science. He gave the world its first seismic network and pioneered the development and use of standardized instruments that, in comparison with their predecessors, were remarkably sensitive, reliable, and precise. He also generated a staggering body of observational data.

While later innovations such as electromagnetic seismographs, electronic amplification of signals, and digital recording methods have sidelined mechanical seismographs like Milne's, most of today's seismometers employ the same basic principles that Milne's did: When the ground shakes, the inertia of a weighted pendulum causes the instrument's frame to be displaced in relation to the pendulum; the resulting motion is amplified; and that amplified motion is recorded as a function of time.

The international seismic network Milne created in the early twentieth century was the forerunner of today's array of seismological networks that monitor seismic activity around the globe. Worldwide earthquake observation efforts have enabled seismologists to study global patterns in seismic activity and to form a better picture of how earthquake forces move through the earth. Today's digital networks can provide researchers with real-time data; in addition, they can help emergency response teams determine where to focus their efforts when a large earthquake strikes a populated area and communication systems are down or overloaded. In some regions, these networks can also generate early-warning information for the public, giving people valuable seconds to act before the most severe shaking begins.

—*Karen N. Kähler*

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See also: Charles Francis Richter.

JOSEPH MONIER

French landscaper

Around the mid-1800's, Monier began experimenting with ways to make concrete planters that were durable and light. His idea for reinforced concrete influenced the construction of buildings and bridges.

Born: November 8, 1823; Saint Quentin La Poterie, France
Died: March 13, 1906; Paris, France
Primary field: Civil engineering
Primary invention: Reinforced concrete

EARLY LIFE

Joseph Monier (mahn-yay) was born into a poor farming family in Saint Quentin La Poterie, near Nîmes in southern France. He was the sixth of ten children. Little is known about his childhood. Joseph and his brothers helped their father in the fields and with landscaping. According to legend, when the local abbey suggested that the fourteen-year-old boy be sent to school, his mother refused, saying that Joseph was too smart for school and would get along fine in life without an education. At nineteen, he was sent to Paris to tend the garden of the duke's palace. He used his evenings to teach himself to read and write.

LIFE'S WORK

Around 1846, Monier became a gardener at the Jardin des Tuileries of the Louvre, whose extensive gardens contained various plants and flowers that attracted visitors from around the world. The expensive and exotic flowers needed to be replanted often, and Monier began considering an alternative to wooden flowerpots, which were not durable and were also easily damaged by weather and plant roots. Clay pots were very fragile as well.

Monier started his own landscaping company in 1849 while working for the imperial palace of Luxembourg. Around this time, concrete began to be used for nonbuilding purposes. For example, structures were covered with a layer of concrete to make them fireproof. Planters made of concrete were easily broken, so Monier began to experiment with the material to make sturdier containers. The only way he was able to make the concrete pots stronger was to increase their thickness, which made the flowerpots very heavy and difficult to move. Monier knew that to be useful in landscaping, flowerpots had to be sturdy but light enough to be moved easily.

Monier probably attended the 1855 World's Fair, held in Paris. On display there was a small ship built by Frenchman Joseph Lambot that was constructed with cement mortar that had been reinforced with iron. Lambot is credited with building the world's first concrete boat and inventing ferrocement. By 1861, Monier's landscaping business had grown and was known for his fashionable use of rocks. He had begun experimenting with new methods for making concrete planters, as well as water basins and troughs. Monier used iron mesh to strengthen the material without the weight of extra concrete.

On July 16, 1867, Monier received his first patent for his system of building iron-reinforced concrete troughs used for landscaping. That same year, he showed his invention at the Paris Exposition. Whereas concrete structures had problems with tensile stress fractures, and iron—though strong, readily available as long pipes, and useful for simple jobs—was expensive and difficult to use in more complex projects, Monier's system of adding a steel frame to the concrete slab solved both problems. French engineer François Hennebique saw Monier's horticulture troughs and basins at the 1867 exposition and started his own construction company. In 1892, Hennebique patented his own method for reinforced concrete construction.

In the years following the Paris exposition, Monier filed for five new patents and six patents building on his original one. In 1868, he obtained a patent for iron-reinforced concrete pipes; the following year, he received one for reinforced concrete panels for buildings. Monier continued to work on new applications, and he obtained a patent for reinforced concrete bridges in 1873. He designed the first bridge using this technique in 1875 at the castle of Chazelet. Only 16.5 meters long and 4 meters wide, the bridge spanned the river. His last patent, issued in 1878, was for reinforced concrete beams. Monier's patents do not contain much technical information. It appears that he producd the material without understanding the science behind the techniques.

During the late 1870's and early 1880's, Monier sold his patent rights to various German and Austrian builders. Among them was Gustav Wayss of Berlin. Wayss understood the importance of reinforced concrete to the construction industry, and through a series of business deals he obtained all Monier's patent rights by 1887. Wayss spent years experimenting to understand the science of reinforcing concrete. He published the results, terming the process the "Monier system." Between 1887 and 1899, Wayss's company built 320 bridges throughout Europe using Monier's design of crisscrossed iron rods under a thick layer of concrete.

Critics of the Monier system pointed out a series of potential flaws. They worried that wet cement would rust the bars, making them porous and breakable. It was also speculated that the iron and concrete would not always bond correctly. This would result in a weak structure, capable of breaking as easily as regular concrete. In order to silence the critics, several tests were carried out. Segments of reinforced concrete were excavated and destroyed to examine the iron rods. The rods were intact and looked as though they had just been forged. Tests were also done on slabs of reinforced concrete that were left outside during the winter months. Monier's system held up under these conditions as well. Thanks to Monier, architects and builders finally had a cheaper, stronger, more pliable material that revolutionized the construction industry.

Despite the value of his inventions and patents, Monier filed for bankruptcy in 1888. His business associates from throughout Europe and his many friends petitioned the French president on his behalf. Monier was grateful, saying that he was happy just to have created an inven-

CONCRETE

Concrete has been a popular building material for more than two thousand years. English engineer John Smeaton developed a cement that hardens under water, called hydraulic cement, around 1756. Portland cement (the dominant type used today), named for its similarity to stone found on the island of Portland, was patented by Joseph Aspdin in 1824. Thirty years later, Englishman William Boutland Wilkinson patented the first reinforced concrete floor slab. It was first used in construction of a home in Newcastle, England, in 1864. Around this time in Paris, Joseph Monier was inventing his method for reinforcing concrete.

In 1878, Thaddeus Hyatt received the first U.S. patent for a reinforced concrete system. After purchasing Monier's patents, the Wayss and Freytag company built 320 bridges throughout Europe by 1899. During the 1890's, François Hennebique began using reinforced concrete for buildings in France. Also at this time, American engineer Ernest Ransome began experimenting with the building material. Ransome developed the twisted square bar system from which many current deformed bar methods evolved. In 1893, a refinery for the Pacific Coast Borax Company in Alameda, California, became the first building in the United States to be constructed with reinforced concrete. In 1906, A. P. Turner of Minneapolis developed the "mushroom slab," a flat slab of concrete that is girderless.

Scientists have since figured out the reasons for reinforced concrete's increased strength. Concrete and steel expand at similar rates when heated and contract similarly when cooled. This means that the two materials do not cause internal cracks when the temperature changes. Second, the lime (calcium carbonate) in the concrete produces a film that coats the steel's surface. The film helps make the steel less susceptible to corrosion. Last, the concrete bonds completely to the surface of the steel. This efficiently transmits the stress and weight between the two materials.

Reinforced concrete does have some flaws. It is easily corroded by salt used to thaw and prevent icing. Using steel that has been specially treated, for example, by a light-green epoxy can slow the corrosion. Certain concrete mixes are also more resistant to the harmful effects of the salt. Poorly made reinforced concrete can be destroyed by freezing and thawing or corrosion. If the steel inside begins to rust, it expands and cracks the concrete.

As technology changes, so does the need for new and better building materials. Hospitals, for example, cannot be reinforced with steel because of the magnets in the magnetic resonance imaging (MRI) machines. Highway tollbooths that use radio signals to read vehicle tags also cannot use steel. A solution to this problem is fabricated plastic that can be as strong as steel. While the plastic version is lighter and often cheaper, it is not fire-resistant.

tion that benefited all civilized people. He died in poverty on March 13, 1906, at the age of eighty-two.

IMPACT

In addition to garden pots, Monier patented ideas for arches, bridges, pipes, floors, and railroad ties. His invention of reinforced concrete changed the face of cities throughout the world. Most of the large buildings in major cities would not be possible without reinforced concrete. The same can be said for a number of bridges.

Several engineering, construction, and architecture textbooks have been written about reinforced concrete. It lowers the cost of the construction and materials, shortens the schedule, and increases occupancy levels, strength, and durability of the building. When completed in 1910, the Paulinskill Viaduct in Hainesburg, New Jersey, was the world's largest reinforced concrete structure. The bridge, built by the Lackawanna Railroad, is 35 meters high and 335 meters long. Today, the longest reinforced concrete arch bridge is the Wanxian in China, spanning 420 meters. In 1955, only 40 percent of U.S. bridges were made of concrete. By 1995, the percentage was up to 70 and still growing. The National Bridge Institute found that 20 percent of steel bridges built since 1955 were deficient. It also found that only 7 percent of all reinforced concrete bridges ever built were deficient.

Reinforced concrete bridges, roads, and buildings are built to withstand hurricanes, tornadoes, wind, fire, and even terrorism. Reinforced concrete was a key building material used in World War II and Cold War bunkers and bomb shelters. The material is also used to build airport terminals, runways, tunnels, and parking garages. Many homes are built on a slab of reinforced concrete.

—*Jennifer L. Campbell*

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See also: Giovanni Branca; Joseph Glidden; John Loudon McAdam; John Augustus Roebling; Frank Lloyd Wright.

JOSEPH-MICHEL AND JACQUES-ÉTIENNE MONTGOLFIER

French aeronautical engineers

The Montgolfier brothers are credited with inventing and developing the hot-air balloon, making it possible for the first time for humankind to fly.

JOSEPH-MICHEL MONTGOLFIER

Born: August 26, 1740; Vidalon-les-Annonay, France
Died: June 26, 1810; Balaruc-les-Bains, France
Also known as: Joseph-Michel de Montgolfier

JACQUES-ÉTIENNE MONTGOLFIER

Born: January 6, 1745; Vidalon-les-Annonay, France
Died: August 2, 1799; Serrières, France
Also known as: Étienne-Jacques de Montgolfier
Primary field: Aeronautics and aerospace technology
Primary invention: Hot-air balloon

EARLY LIVES

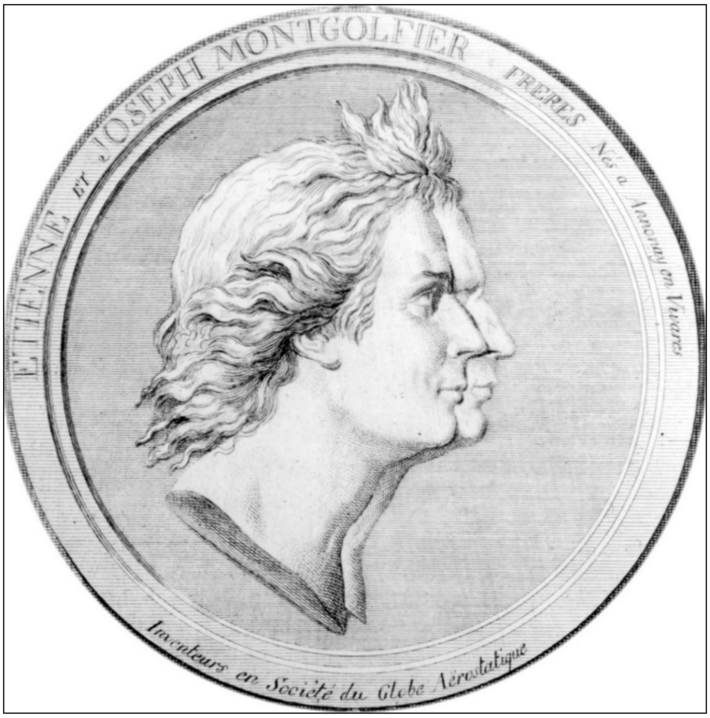
Joseph-Michel (zhoh-zehf mee-shehl) and Jacques-Étienne Montgolfier (ay-tyehn mahn-gahl-fyay) were two of sixteen children born into a family of prominent paper manufacturers living near the town of Vidalon-les-Annonay in the Ardèche Department of southeastern France. The more imaginative of the two brothers, Joseph was a genial, absentminded tinkerer whose interest in science was at odds with the strict theological curriculum of his Jesuit college in nearby Tournon. He ran away from the school twice, the second time to sell dyes of his own manufacture at fairs and markets. His father sent him for a time to Paris, but he returned to the region of his birth to run competing paper mills in partnership with his brother Augustin. He married his first cousin, Thérèse Filhol, in 1771.

Jacques-Étienne showed more self-discipline than his brother Joseph and, unlike him, gained a solid background in mathematics and mechanics. He was the youngest son of the family and went on to study architecture at the Collège Sainte-Barbe in Paris. With the death of his older brother Raymond, however, he was called home in 1772 to take over the family paper business. It was an unexpected development, but one to which he apparently gladly acquiesced. Soon after his return, he met and fell in love with Adélaïde Bron, a novice nun who had just been released from her vows. The two were married in 1774.

LIVES' WORK

Joseph was the more creative of the two brothers and seems to have daydreamed for years about traveling through the air. At the same time, he was profiting from the knowledge and experience of others. A cousin who had studied in Paris shared news of the experiments of English scientists Henry Cavendish and Joseph Priestley in isolating and identifying various gases. Cavendish had discovered what is now known as hydrogen, an element far lighter than air, while Priestley had discovered oxygen. Subsequently, Joseph was able to read a translation of Priestley's *Experiments and Observations on Different Kinds of Air* (1774).

Although Joseph experimented first with small hydrogen-filled balloons, he had far greater success using heated air. He was living in the city of Avignon at the time of his first successful experiment, which involved


ETIENNE ET JOSEPH MONTGOLFIER
FRERES Nés a Annonay en Vivarez
Inventeurs en Société du Globe Aérostatique

Brothers Joseph-Michel and Jacques-Étienne Montgolfier. (Library of Congress) lighting a small fire beneath a construction of wood and silk. He promptly rushed home to share his discovery with his family, and in November, 1782, he managed to send a second version of his invention seventy feet into the air and keep it aloft for a minute. His enthusiasm suddenly awakened, the more practical Jacques-Étienne now joined Joseph in constructing a larger version of the invention some nine feet on a side. Launched on December 14, 1782, it rose with such force that it broke its rope and ascended to a height of about six hundred feet. On April 25 of the following year, the brothers released a balloon about thirty-five feet in diameter and watched it rise to a height of about one thousand feet.

Next, the brothers planned a public demonstration of their invention, constructing a balloon of burlap and paper about 110 feet in circumference. Launched on June 4 or 5, 1783, from an open area near the center of Annonay, it reached a height of some six thousand feet and was witnessed by a crowd of onlookers that included the General Council of the region.

Jacques-Étienne now proceeded to Paris to construct a huge balloon fit for a grand public display. It was launched early in the afternoon of September 19, 1783, at the royal palace of Versailles and carried a sheep, a chicken, and a duck beneath it in a wicker basket. Spectators included representatives of the Académie des Sciences as well as King Louis XVI and his wife, Marie Antoinette. The balloon rose to a height of some seventeen hundred feet and eventually landed about two miles away. Subsequently, the king ennobled the Montgolfier family, allowing its members to add "de" to their name.

The next logical step involved human flight, and it was not long in coming. Although he did not speak about it openly, Jacques-Étienne seems to have taken a ten-minute balloon trip on October 12, 1783. Joseph, who had not cared to follow his brother to Paris, apparently made his own flight on November 18 near the city of Lyon. A public display of tethered human flight took place in Paris on October 15, when physician Jean-François Pilâtre de Rozier made several short ascents in one of the Montgolfiers' balloons. Pilâtre de Rozier and his friend François Laurent d'Arlandes made the first untethered flight on November 21 over the roofs of Paris.

In honor of their accomplishments, the Montgolfier brothers were accepted into the Académie des Sciences on December 10, 1783. Jacques-Étienne returned from Paris to manage his father's paper factory in 1784, and during the French Revolution (1789-

THE HOT-AIR BALLOON

Although Joseph-Michel Montgolfier experimented with a number of devices, his most important invention is the hot-air balloon, which he developed with the help of his brother Jacques-Étienne. Many stories have grown up around his early fantasies and observations, but he seems to have experimented first with small constructions of paper and silk filled with hydrogen. He was able to produce the newly discovered gas relatively easily, but he found that it leaked through all the lightweight materials he had available to him.

According to an account he gave later, Joseph was considering unsuccessful French and Spanish attempts to take the fortified peninsula of Gibraltar from the British in 1782 when it occurred to him that the same force carrying smoke up his chimney might be harnessed to invade the peninsula from the air. Accordingly he built a three-by-three-by-four-foot frame from wooden sticks, enclosed all but the bottom of it in silk, and lit a small fire beneath it. Shortly it rose to the ceiling, lifted by the heated air trapped within (although Joseph mistakenly believed that it was the smoke that was creating the force).

Joseph and Jacques-Étienne sometimes employed paper (of which they had an ample supply) in their later models, as well as burlap and silk lined with paper. A small metal stove hanging directly beneath an opening in the bottom of the balloon held the fuel—straw, sticks, and so on—to be burned, while any passengers were carried in a suspended basket.

Although the Montgolfier brothers may not have understood it thoroughly, their balloons operated on the principle of buoyancy, which involves the upward pressure upon an object whose overall density is less than that of the fluid (liquid or gas) in which it is submerged. Like hydrogen, heated air is less dense than the air surrounding it, and it forces the balloon to rise to a level at which its density matches that of the air outside it.

In practice, early balloon flights were limited by the ability to maintain a heat source (without at the same time setting fire to the balloon), although the development of liquid propane as a fuel would eventually provide a practical solution. Balloonists soon learned to carry sand as ballast and to adjust their altitude by releasing it over the side. In addition, designers built adjustable vents in their balloons that could be opened to release hot air as necessary. Because hot-air balloons cannot be steered, they are generally at the mercy of the prevailing winds, but technical advances have made their recreational use common throughout the world.

1799) he worked in favor of the deposed monarchy. He died in the town of Serrières, near Vidalon, in 1799.

Joseph had continued to experiment with other inventions. One was a version of parachute, to which he tied a sheep and dropped it from a tower. He also helped develop the hydraulic ram, an invention for raising water. In 1797, he moved to Paris, where he was given a sinecure with the museum and technical school known as the Conservatoire National des Arts et Métiers. He was also instrumental in founding the Société d'Encouragement pour l'Industrie Nationale, and he was elected to the Institut de France, the parent body of the Académie des Sciences. He died in the southern French town of Balaruc-les-Bains in 1810.

IMPACT

The principles involved in buoyancy had been recognized since the days of Greek mathematician Archimedes of Syracuse (c. 287-212 B.C.E.), and the ancient Chinese are known to have used small hot-air balloons for signaling purposes during warfare. Brazilian-born priest and scientist Bartolomeu de Gusmão may have employed heated air to raise a small balloon as early as 1709. However, Joseph-Michel Montgolfier and his brother had the knowledge, means, and opportunity to experiment rigorously with the possibilities of lighter-than-air flight, and they are generally and rightly acknowledged as its inventors.

Within less than a year of Joseph's initial modest success in Avignon, the first flights involving humans were made, and other advances came in quick succession. The Montgolfiers' early experiments spurred the efforts of other scientists and inventors and captured the imagination of laypeople around the world. Talk of "aerostats" (balloons) and "aerostatics" (the science involved in launching and flying them) became commonplace, as did images of the colorfully decorated craft floating above cities and the countryside.

Subsequently, hydrogen- and helium-filled balloons were employed in warfare, and eventually much larger craft, known as blimps and dirigibles, were created that were capable of transoceanic flights carrying freight and passengers. Hot-air balloons are still commonly flown by individuals for recreation.

—*Grove Koger*

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See also: ʿAbbas ibn Firnas; George Cayley; Louis-Sébastien Lenormand; Joseph Priestley; Faust Vrančić; Wilbur and Orville Wright.

ROBERT MOOG

American electrical engineer

Moog introduced the electronic synthesizer to popular music by creating an electronic keyboard that could be played with the same expressive range as a saxophone or a cello. The Moog synthesizer created an entirely new sound and a number of new genres, changing popular music forever.

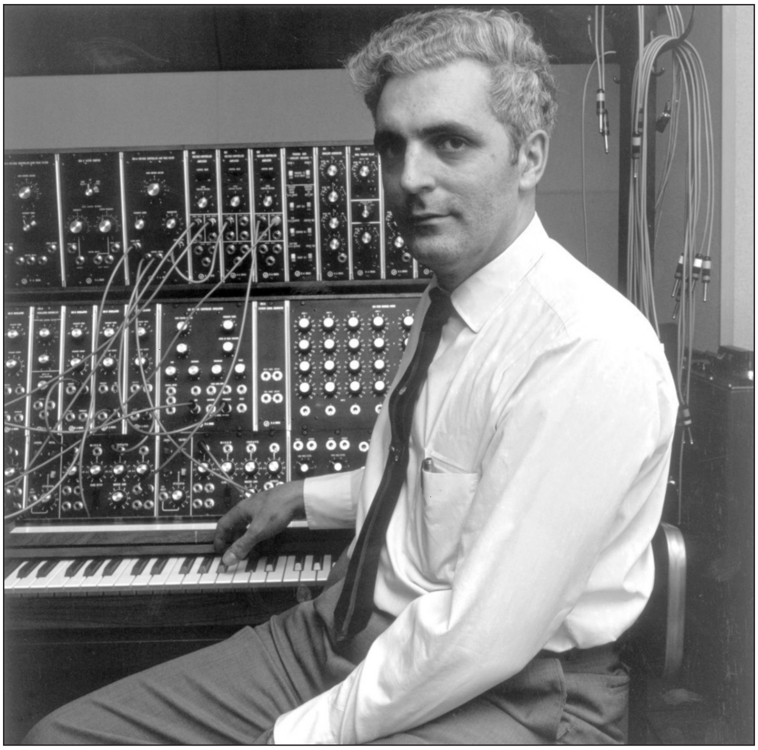
Born: May 23, 1934; New York, New York
Died: August 21, 2005; Asheville, North Carolina
Also known as: Robert Arthur Moog (full name)
Primary fields: Electronics and electrical engineering; music
Primary invention: Moog synthesizer

EARLY LIFE

Robert Arthur Moog (mohg) was born in New York City in 1934 and raised in Flushing Meadows, New York, by a mother who was insistent that he would become a concert pianist, making him practice for hours each day. Moog described himself as an adolescent "class brain" and a social outcast among his peers. It was with his father that he was able to find some solace. Moog was very interested in his father's passion, electronics, yet it would be a combination of the worlds of music and electronics that would be Moog's key to fame.

In the late 1940's, Moog discovered the theremin, an electronic musical instrument that one plays by waving one's hands around the instrument's two antennae, which control pitch and volume. The tones produced by a theremin were so mysterious and dramatic that the instrument may be best known for its use in the 1951 film *The Day the Earth Stood Still*. In 1949, at the age of fifteen, Moog built his own theremin from plans he found in a magazine. He began modifying his instrument and soon developed a design of his own.

Moog was able to find more of a niche for himself at the prestigious Bronx High School of Science. He continued to pursue his intellectual passion through education as he earned an undergraduate degree in physics from Queens College. From there, he packed up his theremin and headed to Cornell University. In 1954, Moog was a graduate student in physics at Cornell when he published an article in *Radio and Television News* in which he provided the plans for building his version of the theremin. Moog also began selling theremins and theremin kits by mail order for $49.95. The demand was so high that he established the R. A. Moog Company and soon had accumulated more than $13,000 in profit, a tidy sum for that era.



Robert Moog sits in front of his synthesizer, with a keyboard and electronic circuits. (Getty Images)

LIFE'S WORK

Moog finished his first doctorate, in engineering physics, from Cornell in 1965, and the R. A. Moog Company had proven profitable. These events led to his work on his second doctorate, in electrical engineering, at Columbia University, where he was beginning to work with a music teacher and composer named Herbert Deutsch on a way of shrinking the room-sized acoustic synthesizers that Radio Corporation of America (RCA) had developed down to an instrument that could be carried onto the stage.

The Moog Synthesizer

In the 1950's, Radio Corporation of America (RCA) constructed a mechanical synthesizer, the telharmonium. The device filled a laboratory and had to be programmed with binary code to make one simple sound. It was not exactly the stuff of which garage bands are made.

Robert Moog's synthesizers were, in 1964, a collection of voltage-controlled electronic music modules. The first module he created was an oscillator that allowed the musician to create a sound wave that varied from the pure and gently pulsing toned sine wave to the grating sound created by sawtooth waves. The next module, called the ADSR (attack, decay, sustain, release) envelope generator, took the wave and defined the way it sounded as it began and ended, its duration and intensity. The third module Moog called the "voltage lowpass filter," and it shaped the texture and color of the wave.

By attaching these modules to others Moog would create, a musician could control the creation and aspects of a sound by turning the appropriate knobs. Moog later added a keyboard as the interface, allowing the musician unprecedented control of the creation of sound. Moog's initial synthesizers were designed as tools for the creation of music in the recording studio, not as performance instruments. The sound that was created was monophonic, not stereo, but the recording techniques of the era were such that entire symphonies could be built from the single notes generated by Moog's early synthesizers.

Moog took the basic synthesizer, which retailed for $10,000, to the 1964 convention of the Audio Engineering Society in New York, where the machine quickly became a sensation among composers. By 1968, Moog had sold dozens of the synthesizers. Early purchasers were Mick Jagger and George Harrison, and the synthesizer began appearing in popular music. However, it was Walter (Wendy) Carlos's hugely popular album *Switched-On Bach* (1968) that both introduced the synthesizer to the general public and, since the album was composed entirely on a Moog synthesizer, alerted the music industry to the musical potential of Moog's invention.

Carlos's success was quickly followed by the Beatles' extensive use of the Moog synthesizer on their final album, *Abbey Road* (1969), and Carlos's venture into cinematic sound tracks with the score to Stanley Kubrick's *A Clockwork Orange* (1971), which featured Moog versions of Ludwig van Beethoven's music. Despite this success, Moog had yet to realize his dream of producing a synthesizer as a stage instrument. Even though some musicians, such as Keith Emerson of Emerson, Lake, and Palmer, would have an entire enormous Moog synthesizer constructed on stage for a performance, Moog wanted a version small enough to be carried by the performer.

In 1970, Moog constructed the first portable synthesizer, the Minimoog, a three-and-one-half-octave electronic keyboard that was small enough for musicians to carry on stage. Even though the digital age and the ability of Asian countries to make cheap knockoffs would soon overtake the Minimoog, the portable analog synthesizer survived long enough to have a permanent impact on popular music and sound recording technology.

Moog had been studying German designer Harald Bode's ideas about transistorized modular synthesizers, and he realized that by using cheap, off-the-shelf voltage-controlled oscillators and amplifiers, he could change the basic tonal characteristics of a sound; that is, one note at a time at least, he could synthesize the sound of any instrument. Moog worked with Deutsch and musician Walter Carlos and began producing synthesizing modules that were connected together via patch cords.

In 1964, Moog was invited to take his analog synthesizer to the convention of the Audio Engineering Society in New York, where his invention garnered a great deal of interest. Moog's first synthesizer cost about one-tenth of RCA's room-sized version, and Moog had made his more user-friendly by adding a keyboard as the user interface. By 1968, Moog had sold dozens of his synthesizers, and his new contribution to music was being heard on the radio in tunes by groups such as the Monkees and the Beatles. Despite this success, the Moog synthesizer had yet to change the face of popular music. That would change with an electronic version of classical works.

In 1968, Walter (who later had a sex-change operation and became Wendy) Carlos released his interpretation of the music of Johann Sebastian Bach, produced entirely on a Moog synthesizer, on an album entitled *Switched-On Bach*. The album was wildly successful and introduced the general public and the recording industry to the potential of Moog's creation.

In 1970, with the release of the Minimoog, Moog achieved his goal of releasing a synthesizer that performers could carry, like an instrument, onto the stage. The now familiar three-octave keyboard freed the musician to take the power of Moog's synthesizer anywhere the musician wished to make music. However, the design of the Minimoog was such that it allowed companies in Asian countries to create cheaper knockoffs. This cut into Moog's profits but spread the gospel of electronic music that eventually led to the Moog sound revolutionizing popular music beginning in the early 1970's. Perhaps the defining moment of the early days of the Moog revolution was the success of Echo and the Bunnymen, a band whose front man, "Echo," was a drum synthesizer.

The Minimoog not only was the synthesizer of choice for the music industry but also brought electronic music to the masses. The Minimoog spread across all musical genres and economic strata. Soon, Minimoogs were appearing in lounge acts at small-town motels. As a result of the success, Moog found himself in a booming business that he was ill-equipped to run. After changing the company's name to Moog Music in 1971, Moog sold the business to rival Norlin Music in 1973.

Moog left Moog Music in 1977 and traveled to the mountains of North Carolina, where he founded Big Briar in 1978. At Big Briar, he went back to his roots: making theremins and developing electronic instruments with unique interfaces. In 2002, Moog was able to recapture the name Moog Music for his company.

While at Big Briar/Moog Music, Moog created such products as the Moogerfooger analog effects modules, which brought the flexibility and creativity of the original Moog modules to all musicians. Moog also brought back the Minimoog Voyager, which incorporated digital features into his original analog design. He died of an inoperable brain tumor on August 21, 2005, in Asheville, North Carolina, at the age of seventy-one.

IMPACT

From the stylized electronic sound of bands like Devo or Kraftwerk to the expansive digital vistas created by keyboardist Keith Emerson of Emerson, Lake, and Palmer, the signature sounds of these bands would not have been possible without what has become one of the most recognizable instruments in the recording industry: the Moog synthesizer. Robert Moog, the father of the Moog synthesizer, has been compared to Les Paul and Leo Fender, the men who are heralded as the fathers of the electric guitar. Just as the electric guitar forever changed the sound and meaning of popular music, so too did the Moog synthesizer.

The Moog synthesizer led to a wave of new sounds and even new genres in popular music (New Wave and electronica, for instance), and Moog became the leader, through his technology, by introducing the music industry and the music consumer to electronic music and the technology that made it possible. The very name "Moog" became synonymous with synthesizers and electronic music.

Moog also forever changed the way music is made. His technology took music out of the realm of elitist art, which required extensive technical expertise to create, and put it into the hands of the masses. As a result, the Moog synthesizer liberated the music creator from the overwhelming task of orchestration, from hours of scrawling notes, years of practicing numerous instruments, and hours of rehearsal with an ensemble before a single performance. Instead, with a Moog, the performer now simply had to caress a keyboard, thus creating full orchestration with Moog's technology instantaneously. Newer versions of the synthesizer will even allow the synthesizer to be hooked to a computer to compose and print perfectly orchestrated sheet music of whatever the musician is playing on the keyboard.

—B. Keith Murphy

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See also: Ray Kurzweil; Hugh Le Caine; Les Paul.

GARRETT AUGUSTUS MORGAN

American businessman

Morgan is best known for two inventions. His breathing device, or safety hood (a precursor to the modern gas mask), was initially used by fire departments and later modified for military use, and his three-armed traffic signal was a forerunner of the modern tricolor traffic light.

Born: March 4, 1877; Paris, Kentucky
Died: July 27, 1963; Cleveland, Ohio
Primary fields: Civil engineering; fire science
Primary inventions: Automatic traffic signal system; safety hood (gas mask); hair-straightening cream

EARLY LIFE

Garrett Augustus Morgan was born in Paris, Kentucky, on March 4, 1877. His father, Sydney Morgan, was the biracial son of a slave and the Confederate colonel John Hunt Morgan, leader of Morgan's Raiders in the Civil War. Garrett's mother, Elizabeth Reed Morgan, was the biethnic daughter of a Native American woman and the black Baptist minister Garrett Reed. Garrett Morgan was the seventh of eleven children.

As a young child, Morgan attended the Branch School located in the African American community of Claysville. By the age of fourteen, he had left school and the family farm and moved north to Cincinnati, Ohio, where he worked as a handyman for a wealthy landowner. To assist him in his efforts to improve his academic skills, Morgan hired a tutor. In 1895, he moved to Cleveland, where he worked for various sewing machine manufacturers and eventually became the only African American sewing machine adjuster, not only making necessary mechanical repairs but also inventing and patenting new machine parts. Among his first inventions were a belt fastener and a zigzag stitching attachment for manually operated sewing machines. In 1896, Morgan married Madge Nelson, but after two years their relationship ended in divorce.

Morgan lived during a period of institutionalized segregation in the United States. As a young man, he realized that even the most talented African Americans had very limited career opportunities. For such individuals, self-employment enabled them to utilize more fully their talents and to earn a worthwhile income. Although African Americans had gained the right to patent inventions, they encountered challenges in manufacturing and marketing them. However, through strong business networks and creative advertising strategies, many minority businessmen were successful in developing, patenting, and marketing their inventions.

LIFE'S WORK

In 1907, Morgan opened his first business to sell and repair sewing machines. One year later, he married Mary Anne Hassek, a Bohemian seamstress, with whom he had three sons. That same year, Morgan helped found the Cleveland Association of Colored Men, an offshoot of the National Negro Business League founded by Booker T. Washington. Morgan's commitment to promoting African American businesses and fighting racial prejudice was demonstrated by his active membership and service as an officer. When the Cleveland group merged with the National Association for the Advancement of Colored People (NAACP) in 1914, he became an NAACP member and maintained membership until his death in 1963.

In 1909, Morgan launched a business with thirty-two employees to manufacture coats, dresses, and suits. As a garment manufacturer, he sought a way to reduce fabric damage by reducing friction on the sewing machine needle. While experimenting with a liquid lubricant for the needle, he discovered that the liquid straightened the fibers of a coarse piece of cloth. After further experimenting, he found that the liquid also smoothed human hair, and he developed it into the first hair-straightening cream. In 1913, he started the G. A. Morgan Hair Refining Company to market the cream and additional cosmetics he developed.

Morgan invented a safety hood in 1912 and patented it two years later as a "breathing device." Worn over the head of a person, the canvas hood had two tubes in front that extended downward to encircle the body and join to form a single tube in the back. Hanging close to the ground, the bottom of the single tube was lined with a moist sponge to filter the incoming air. A metal tube inside the hood included a mechanism that prevented smoke from entering as the user inhaled and exhaled air. A nonpressurized air supply was available from a backpack reservoir. Morgan intended the device to be used by firemen, engineers, chemists, and others whose jobs placed them in danger of inhaling toxic fumes or air that contained hazardous dust particles. The National Safety Device Company, with Morgan as its general manager, was established to manufacture and sell the hood. In 1914, at the Second International Exposition of Safety

TRAFFIC SIGNALS

As an inventor and businessman, Garrett Augustus Morgan was financially successful. He was among the privileged Cleveland residents to own an automobile and experience the chaotic road conditions resulting from pedestrians, bicycles, horse-drawn carriages, and automobiles vying for the right of way. After witnessing a terrible accident, Morgan realized that better traffic signals were needed to prevent future catastrophes.

Prior to Morgan's traffic signal, most of the existing signals featured only two positions: stop and go. Manually operated, these two-position traffic signals were an improvement over no signal at all, but because they allowed no interval between the stop and go commands, collisions at busy intersections were common.

Another problem with the two-position traffic signals was the susceptibility to human error. Operator fatigue invariably resulted in erratic timing of the stop and go command changes, which confused both drivers and pedestrians. At night, road conditions were often chaotic because no traffic officers were on duty and motorists simply ignored the signals.

Morgan's mechanical traffic signal was a T-shaped pole unit that featured three positions: stop, go, and an all-directional stop position. The third position halted traffic in all directions before it allowed travel to resume on either of the intersection's perpendicular roads. This feature not only made it safer for motorists to pass through intersections but also allowed pedestrians to cross more safely.

At night, or at other times when traffic was minimal, the lighted Morgan signal could be positioned in a half-mast position, warning approaching motorists to proceed through the intersection with caution. Morgan also included optional bells that could be used as alarms. The half-mast position had the same signaling effect as the flashing red and yellow lights of modern traffic signals. The device made streets safer for pedestrians and was also used at railroad crossings.

Morgan's traffic management technology was used throughout North America until it was replaced by the red-, yellow-, and green-light traffic signals currently used worldwide. Morgan eventually sold the rights to his traffic signal to General Electric for $40,000. Shortly before his death in 1963, Morgan was awarded a government citation for the traffic signal.

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and Sanitation in New York City, the device won first prize, Morgan was awarded a gold medal, and sales increased as fire departments of many cities adopted the hood for general use. Morgan received a U.S. Navy contract for the devices one year later. When gas masks were needed by soldiers to protect them from the effects of poisonous gases such as chlorine, a modified Morgan Safety Hood was among the devices tested and used by the British government during World War I.

On July 24, 1916, an explosion occurred in a Cleveland Water Works tunnel 250 feet below Lake Erie. The tunnel quickly filled with smoke, dust, and poisonous gases and trapped thirty-two miners. After several rescue attempts proved futile, Morgan was contacted. With the help of his brother Frank and a neighbor, William Roots, Morgan gathered safety hoods and rushed to the scene of the disaster. At the site, the Morgan brothers, initially unable to convince the discouraged rescue workers to join them, slipped on the hoods and entered the tunnel. Once the brothers began to successfully retrieve bodies, others donned hoods and rejoined the recovery effort. Although the men were unable to save all of the victims, they were able to save many who otherwise would have died. While Morgan's heroism and safety hood were impressive and photographically documented, little mention of his role appeared in Cleveland news reports, and he did not initially get the credit he deserved. Morgan eventually received awards from several civic organizations and honorary membership in the International Association of Fire Engineers. However, he never received the Carnegie Medal for heroism that had been awarded other rescue workers he had assisted and provided with safety hoods.

Morgan lived during the era when automobiles were becoming the preferable mode of transportation. After witnessing a terrible accident between an automobile and a horse-drawn carriage, he sought to develop a way to automatically direct traffic without operator intervention. Morgan was the first inventor to apply for and acquire a U.S. patent for an automatic three-position traffic signal. His device included a position for an all-directional stop and a position that permitted motorists to proceed with caution. The T-shaped signal post also had lights and alarms. The patent was granted on November 20, 1923. Morgan later had the technology patented in Great Britain and Canada. Although he formed the G. A. Morgan Safety System Company to manufacture the traffic signal, he later decided to sell the patent to General Electric.

Morgan was active in Cleveland's African American community. He founded a newspaper, the *Cleveland*

Call, which he published from 1920 to 1923. The newspaper, now known as the *Call and Post*, is published in Cleveland, Columbus, and Cincinnati. Morgan purchased land in Wakeman and founded the Wakeman Country Club, the first African American country club in Ohio. He was awarded an honorary degree from Western Reserve University and helped found a black fraternity, Alpha Phi Alpha, on its campus. In 1931, he ran as an independent candidate for Cleveland's city council but was not elected. Morgan developed glaucoma in 1943 and eventually lost 90 percent of his sight. In spite of the disease, he persisted in working on his inventions. One of his last was a self-extinguishing cigarette. He died in Cleveland on July 27, 1963.

IMPACT

During his life, Morgan was a respected entrepreneur and inventor. His most notable inventions, the safety hood and the traffic signal, helped to resolve safety issues of his time. The safety hood was adopted for both fire department and military use. Morgan's traffic management technology was used throughout North America until it was replaced by the red-, yellow-, and green-light traffic signals currently used around the world. He served as a catalyst to promote transportation education and the development of intelligent transportation systems (ITS). Morgan received many awards for his contributions to public safety and has been recognized in the United States as the "father of transportation safety technology."

Although he was from a poor family, had little formal education, and lived during an era of overt discrimination in the United States, Morgan was self-taught and steadfast in the pursuit of all of his diverse goals. As an inventor, businessman, newspaper publisher, and politician, he inspired many African Americans to overcome economic, educational, social, and political inequities based on race.

Several public schools in cities around the United States, including Chicago, Cleveland, and New York City, were later named in his honor. The district of Claysville, Kentucky, was renamed Garrett Morgan Place. Garrett A. Morgan Boulevard in Prince Georges County, Maryland, and the Washington Metro Morgan Boulevard Station are also named in his honor.

—*June Lundy Gastón*

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See also: Nick Holonyak, Jr.; Shuji Nakamura; Madam C. J. Walker.

Samuel F. B. Morse

American painter

Generally considered the inventor of the electric telegraph and the Morse code of dots and dashes, Morse introduced the first practical method of transmitting messages instantaneously over long distances.

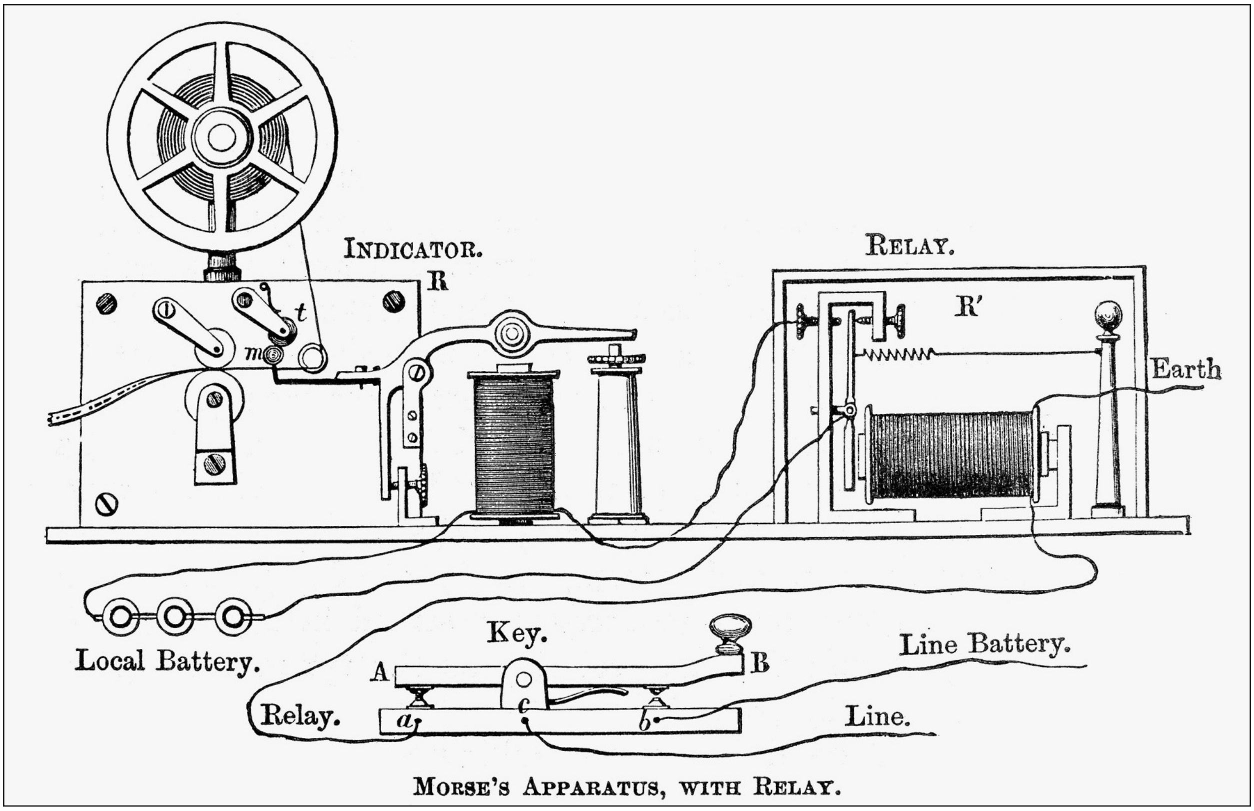
Born: April 27, 1791; Charlestown, Massachusetts
Died: April 2, 1872; New York, New York
Also known as: Samuel Finley Breese Morse (full name)
Primary fields: Communications; electronics and electrical engineering
Primary inventions: Electric telegraph; Morse code

Early Life

Samuel Finley Breese Morse was the eldest son of the Congregationalist minister and noted geographer Jedidiah Morse and Elizabeth Ann Breese. From an early age, he showed a talent for art, drawing miniatures of his classmates at Yale College. By the end of his time at Yale, he was set on becoming a painter, but he also had demonstrated an interest in science, including the new discoveries concerning electricity. In general, he exhibited wide-ranging interests, so much so that his parents were concerned that he was too much of a dilettante, lacking perseverance in any one field.

His parents were also not enthusiastic about his decision to become a painter. His father apprenticed him to a publisher in Boston before relenting and allowing him to go to London to study art with the American painter Washington Allston. The young Morse spent three years in England, developing an interest in painting large historical and mythological subjects and also developing strong patriotic views, speaking up in defense of his homeland during the War of 1812 between the United States and Great Britain.

On his return home, Morse found little market for his grand painting projects and instead became a painter of



Samuel F. B. Morse's experimental telegraph with relay, 1837. (The Granger Collection, New York) portraits, traveling around New England and also to Charleston, South Carolina, to paint pictures of ordinary people. He did, however, embark on a major painting of the House of Representatives in 1821, but it made him little money. Discouraged about his painting career, Morse contemplated other options, including going into the ministry and becoming an architect. He also dabbled in inventions, patenting a pump for fire engines or boats and later devising a machine for carving marble.

In 1826, Morse helped found and became the first president of the National Academy of Design, an organization of young painters formed in opposition to the older, conservative American Academy of Fine Arts. In 1829, feeling the need for more training in art, he returned to Europe to study, coming home again in 1832 on the ship *Sully*. On his return, stimulated in part by what he had seen in Rome, he became an anti-Catholic pamphleteer. He also obtained a position as a professor of fine arts at the new New York University. Most important of all, he came back with an idea for a new invention, the electric telegraph.

The Electric Telegraph

Samuel F. B. Morse's telegraph was not the only one being worked on in the early nineteenth century, but it turned out to be the simplest and most practicable. In England, William Fothergill Cooke and Charles Wheatstone created an electric telegraph that used multiple wires and needles to indicate letters, but this was much more complicated than Morse's invention, a single-wire system that depended simply on the duration of the signal: A short signal meant a dot, a long one a dash. With the dot-dash Morse code, this signaling system allowed messages to be conveyed easily. The original Morse telegraph included a battery to send the electric signals via a port-rule constructed out of printers' materials. At the receiving end, a register activated by an electromagnet recorded the electric signals as marks on a paper tape, using a pencil or, later, a stylus.

At first, Morse wanted to record a series of lines, with the number of lines corresponding to a whole word. This was a cumbersome method requiring a specially constructed dictionary, and he soon abandoned it for Morse code, in which each dot-dash combination corresponded not to a word, but to a letter in the alphabet.

Morse's assistant, Alfred Vail, refined the transmitter by replacing the port-rule with a simple key that, when depressed or lifted, would create or break the circuit, thus sending the dots and dashes. Eventually, it was discovered that telegraph operators could understand messages from the clicking sounds made by the receiver; thus, instead of working from the paper tape, they would transcribe the sounds, handwriting or later typewriting the message as they heard it. To facilitate this process, a device called the sounder was introduced.

Telegraph wires were generally strung overhead on wooden poles, with glass knob insulators where the wire met the wood. At first, copper wires were used, but iron was later found to be more reliable. For underwater transmission across the Atlantic, the wires were placed inside pipes with special insulation.

Life's Work

On the voyage home on the *Sully*, Morse happened to engage in a casual conversation with a shipboard companion, Dr. Charles Jackson, about electricity and the relatively new subject of electromagnetism, two phenomena that did not yet have any practical application. Jackson said that an electric current could continue undiminished through any length of wire, prompting Morse to comment that if this was true, then there could be instantaneous communication over long distances.

Inspired by this notion, Morse began sketching devices that could harness electricity to send messages. Morse had learned a little about electricity at Yale, where one of his professors once sent a current through a class of hand-holding students. He had also been interested enough in the subject to attend lectures on electromagnetism in New York. Jackson and Morse thought they were the first to think of an electric telegraph, but in fact the idea had been suggested decades before, and attempts to produce a working model were under way independently in England and Germany.

When Morse first got home, in 1832, he turned away from the telegraph temporarily to return to his career as an artist and professor, and also to engage in anti-Catholic politics. He became president of the American Protestant Union and twice ran unsuccessfully for mayor of New York on an anti-Catholic and anti-immigrant platform. It was only in 1837, hearing of rival attempts to create a telegraph in Europe, that Morse returned to the project, perhaps also being motivated by being turned down for a commission to do a painting in the Capitol Building. After this date, he essentially abandoned painting for work on the telegraph, and he began using his rooms at New York University for telegraphic experiments.

To assist him, Morse enlisted the aid of Leonard Gale, a chemistry professor at the university, who informed him of the electromagnetic researches of Joseph Henry, which included ringing a bell at a distance through a wire. Based on this information, Morse improved his original telegraph by using a stronger battery and a stronger magnet so that he could send a message ten miles instead of forty feet.

Morse also enlisted the aid of Alfred Vail, a former student of his with mechanical aptitude and a father with money to invest. In 1838, Morse demonstrated his telegraph to the Commerce Committee of the House of Representatives and won the support of its chairman, F. O. J. "Fog" Smith, who became another partner. Smith provided legal, business, and political advice, but Morse was to regret his association with him; most accounts describe him as unscrupulous, and he ended up opposing Morse rather than helping him.

Despite a recommendation from the Commerce Committee in 1838, it was not until 1843 that Congress approved funding for an experimental telegraph line from Baltimore to Washington. Work on this line ran into difficulties because of problems with the underground cable. Morse eventually decided to install the telegraph wires overhead on poles instead. This system worked, and on May 24, 1844, what is known as the first formal telegraph message went out on Morse's telegraph line: "What hath God wrought?" (a Bible quotation). This was not really the first message, for Morse had sent many test messages before this date. Earlier in May, when the Whig Party nominated Henry Clay at its presidential convention in Baltimore, Morse's telegraph was able to get word to Washington an hour and a half before the news could reach there by train.

Besides the telegraph, Morse also worked on the new art of photography, being one of the first to introduce the invention of Jacques Daguerre to the United States and perhaps the first to take a photographic portrait. He also worked with Samuel Colt on using electricity to set off underwater mines. Aside from that, for the rest of Morse's life his main work was his telegraph, which astonished the public and revolutionized communications, business, the military, and the press. His invention brought him many honors both at home and abroad, including an honorary doctorate at Yale and the French Legion of Honor. However, it also involved him in various disputes and lawsuits over the rights to the telegraph, with various former partners and associates claiming to be the true inventor of the device or of the Morse code of dots and dashes that was used to transmit messages.

In 1854, the Supreme Court finally ruled that Morse was the inventor of the telegraph and entitled to patent protection, but disputes continued even after that. For instance, the heirs of Morse's assistant, Alfred Vail, complained to Morse's heirs that it was Vail who had invented Morse code. Most commentators, however, agree that the code was really Morse's invention.

During the Civil War, Morse, though a Northerner, sympathized with the South, wrote in favor of slavery, and became involved with the so-called Delmonico's conspiracy, a failed attempt to overturn the Emancipation Proclamation. Morse originally wanted to sell the rights to the telegraph to the U.S. government but found it was not interested. The result was that private telegraph companies sprang up in which Morse invested and through which he accumulated a substantial fortune, enough to buy a home in New York City and an estate (Locust Grove) near Poughkeepsie, New York. In 1871, the year before he died, a statue of him was erected in New York's Central Park at a ceremony attended by ten thousand people.

IMPACT

Morse's electric telegraph revolutionized communications in the United States and around the world. Before its introduction, communication at a distance had to be done by transportation, that is, by physically conveying a message by horseback or by train. The only exception was visual signaling, for instance through bonfires, smoke signals, or semaphore systems, but these depended on visibility and good weather and were much slower than electric communication. At first seen by some as magical and by others as a hoax, the telegraph quickly transformed various aspects of American life. News from afar began to be reported within hours instead of days, and the newspapers eventually banded together to form the Associated Press to more efficiently use the telegraph.

Although some hoped that this miraculous form of communication would bring people together and lead to peace and brotherhood, in fact one of the main uses of the telegraph was by the military, for instance during the Civil War. The telegraph was also enthusiastically adopted by business and facilitated the growth of nationwide corporations; in fact, one of the first such corporations was a telegraph company, Western Union, which by 1866 had absorbed all its rivals. Eventually, the telegraph was superseded by the telephone, radio, the Internet, and e-mail, but all those other forms of communication at a distance in a way came out of the telegraph, which was the Internet of its day.

—*Sheldon Goldfarb*

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See also: Edwin H. Armstrong; Alexander Bain; Alexander Graham Bell; Karl Ferdinand Braun; Samuel Colt; William Fothergill Cooke; Louis Jacques Daguerre; Lee De Forest; Thomas Alva Edison; Reginald Aubrey Fessenden; Elisha Gray; Oliver Heaviside; Joseph Henry; Lord Kelvin; Guglielmo Marconi; Charles Wheatstone.

ERWIN WILHELM MÜLLER

German physicist

Müller invented three different microscopes: the field-emission microscope, the field-ion microscope, and the atom-probe field-ion microscope. He was the first person to see an image of an individual atom. His inventions allowed scientists for the first time to view surfaces at an atomic level.

Born: June 13, 1911; Berlin, Germany
Died: May 17, 1977; Washington, D.C.
Primary field: Physics
Primary inventions: Field-emission microscope; field-ion microscope; atom-probe field-ion microscope

EARLY LIFE

Erwin Wilhelm Müller (MYOO-lur) was the only child of Wilhelm M. and Käthe Müller (née Teipelke). Wilhelm was a construction worker who specialized in plastering ceilings of houses. Erwin worked part-time as a research assistant (1932-1935) while attending Technische Hochschule in Berlin-Charlottenburg (now Technische Universität Berlin). He received his engineering diploma in 1935 and his doctoral degree with a physics emphasis in 1936. His mentor was the Nobel Prize winner Gustav Hertz.

Being of Jewish descent, Hertz had been forced to resign his university post in 1935. He took Müller with him to the Siemens Research Laboratory, where Müller worked for two years and invented in 1936 the field-emission microscope (FEM), which could achieve near-atomic resolution. In 1937, Müller left Siemens to become the director of research and development at the Stabilovolt Company in Berlin, where he worked from 1937 until 1946. When the Berlin laboratory was destroyed by bombs during World War II, Müller tried to rebuild in Altenburg and in Dresden. Fortunately for science, he was not killed during the firebombing of Dresden in 1945.

Müller was not a member of the National Socialist Party and therefore was not able to obtain a university post until after the war in 1950. Nevertheless, his outstanding research protected him from having to serve in the army. In 1939, he married Klara Thüssing. The couple had one daughter, Jutta, in 1940. The conditions were so bad in Germany immediately after the war that they lived on a nine-hundred-calorie diet. They scavenged food from freshly harvested fields and used marble from a cemetery to make baking powder for bread. During 1946-1947, Müller walked several miles each day to teach physical chemistry at the Technical Institute in Altenburg.

LIFE'S WORK

From 1947 to 1951, Müller worked at the Kaiser Wilhelm Institute for Physical Chemistry in Berlin. There he invented in 1951 the field-ion microscope (FIM), which was capable of atomic resolution. He also taught at the Technical University of Berlin, beginning in 1950, when he finally received his habilitation (teacher's certificate). In 1951, he became a professor at the Free University of Berlin. Müller moved his family to Pennsylvania in 1952 and accepted a position at Pennsylvania State University. Conditions were still difficult in Germany, and Pennsylvania reminded Müller and Klara of rural Germany. Müller became an American citizen in 1962. He worked the rest of his career at Pennsylvania State University, becoming a research professor in 1955, the Evan Pugh Professor of Physics in 1968, and professor emeritus in 1976, when he retired.

Müller's doctoral work had been a study of electrons emitted from a material by applying an electric field to the material. His dissertation was on "The Dependence of Field Electron Emission on Work Function" (1936). The work function of a material is the minimum energy required to emit an electron from the surface. During his experiments, Müller developed the field-emission microscope. The FEM holds a sample formed into a sharp point in a vacuum chamber and coated with a fluorescent material. When a negative electric field is applied to the point, electrons are emitted from the surface of the point. The electrons travel perpendicular to the surface, causing the electron current density to be magnified on the fluorescent screen and producing a magnified image of the surface. The electron current densities depend on the electric fields, and the work function depends on the emitter surface.

Müller's first experiments were not successful, as the electron emissions came from any group of atoms protruding from the surface. There had not been a way to produce a truly smooth surface. Müller then changed the sample point so that it could be heated. The heating cleaned the surface of contamination by causing the contaminants to vaporize. More important, the heating smoothed any rough spots. The surface now was imaged on the fluorescent screen. Not only was Müller able to measure electron emission as he varied the work function

THE FIELD-ION MICROSCOPE

It has been said that Erwin Wilhelm Müller's most valuable contribution to science was the invention of the field-ion microscope (FIM), built in 1951. The FIM was developed because it had long been Müller's goal to produce a microscope that would image individual atoms. His first FIM was produced using field-emission microscope (FEM) equipment. A sample in a sharp point form (less than a 50-nanometer-tip radius) was placed in an ultra-high-vacuum container lined with a fluorescent coating. The container was filled with hydrogen gas. The atoms of the gas adsorbed on the sample. When a high positive voltage (5,000-10,000 volts) was applied, the atoms were ionized and repelled by the electric field. The direction of travel was perpendicular to the surface, so the atoms spread out, producing on the fluorescent coating an image of the surface. The hydrogen gas supplied a continuous source of atoms to be ionized. The first image was weak, but rows of individual atoms were discernible. The magnification was in the range of millions.

The first images were only the atoms on edges of protrusions. The images were improved with field-induced surface dissolution (field evaporation). The sample tip was made smooth by a large electric field, and all of the small projections were evaporated off the sample. It was also discovered that helium gas would work better than hydrogen gas, which is flammable. A great improvement involved cooling the sample to a cryogenic temperature. The earlier FEM and FIM had to be placed in a cryogenic chamber to cool the sample, but Müller devised a cold finger to cool it, simplifying the process. FIM could image all of the atoms of a surface of a solid.

Before the invention of the FIM, surface features were only theory. Now studies could be made of individual vacancies, interstitial replacements, dislocations, grain boundaries, surface corrosion, radiation damage, and other surface phenomena. The FIM allowed the study of different planes of crystals. Field-emission energy distributions could more accurately be studied and were found, surprisingly, to have a narrow range of energies.

by causing layers of metal to adhere to the sample point, but he also could view the surface of the material. The FEM was a boon to scientists studying surfaces and surface phenomena.

Müller wanted to be able to identify atoms chemically, so he set out to invent the atom-probe field-ion microscope (APFIM). The microscope had a probe hole to limit the area of study to one atom or to a small group of atoms. A drift tube was added to measure the time of flight of ejected atoms. The APFIM holds a sample formed into a sharp point, situated in an ultra-high-vacuum chamber, and cooled to very low temperatures (20 to 100 kelvins, or –253° to –173° Fahrenheit). A particular atom is selected by moving the tip to place that atom over the hole probe. The atom is ionized by a positive electrical or laser pulse. The electric field provides the momentum for the ion to travel the length of the drift tube to the detector. A measurement of time between the pulse and the arrival of the atom at the detector is used to calculate mass. The composition of a surface can also be accurately determined. Each layer can then be peeled off, producing a three-dimensional map of a solid. The APFIM provided proof of different isotopes, because each isotope could be measured individually.

Besides his work with these microscopes, Müller described the principle of the imaging field-desorption mass spectrometer. He also induced adsorption of noble gases by electric field effects and formed noble gas-metal molecular ions. He studied the patterns of multilayer field desorption, and he published on the precise measurements of the energy distribution of field-emitted electrons.

Müller published some 211 research papers and several books during his career. He was honored with many awards, including those from the Technische Hochschule in Berlin-Charlottenburg (1936), the Instrument Society of America (1960), the Franklin Institute in Philadelphia (1964), the Chemical Society of London (1969), the American Vacuum Society (1970), the city of Philadelphia (1970), and the American Physical Society (1972). He was awarded two honorary doctorates. Near the end of his career, Müller suffered from throat cancer, but after retirement he seemed to be recovering. He died of a stroke in Washington, D.C., at a meeting of the National Academy of Sciences in 1977. He was awarded the National Medal of Science, which was accepted by his daughter at a White House ceremony in November, 1977.

IMPACT

The field-emission microscope could resolve surface features that were as small as 2 nanometers. With the FEM, scientists could study the surface-layer rearrangement and surface diffusion. For twenty years, FEM was the best tool with which to study surfaces. Information gained from FEM experiments have proven valuable in flat-panel image displays and in vacuum electronics. The field-ion microscope had improved resolution compared to the FEM: one twenty-five-hundredth of a nanometer, the atomic level. The FIM offered visible proof that atoms existed. The magnification was on the order of one million times. The surface could be studied atom by atom, leading to atomic resolution metallurgy and materials research.

In 1967, Müller invented a method to select the atom to be investigated and to measure the mass of that atom by using time-of-flight calculations. Thus, isotopes of the same element could be detected in a surface.

In order to make his microscopes work, Müller had to develop high-vacuum techniques. He was able to produce vacuums of 10^{-12} torr many years before other fields of science reached that vacuum. His use of barium getters and other metal vacuum getters was a valuable step forward for vacuum technology.

—*C. Alton Hassell*

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See also: Gerd Binnig; Dennis Gabor; James Hillier; Heinrich Rohrer.

KARL ALEXANDER MÜLLER

Swiss physicist

Müller, with J. Georg Bednorz, made the breakthrough discovery of high-temperature superconductivity in a new class of ceramic materials.

Born: April 20, 1927; Basel, Switzerland
Primary field: Physics
Primary invention: High-temperature superconductors

EARLY LIFE

Karl Alexander Müller (KAHRL AL-ihg-ZAN-dur MYOO-lur) was born in Basel, Switzerland, in 1927, but the early years of his life were spent in Salzburg, Austria, where his father, Paul Rudolf Müller, was studying music. His mother, Irma (Feigenbaum) Müller later traveled with Karl to Dornach, a few miles south of Basel, where they lived with his grandparents. Since his grandfather had become successful in the chocolate business, mother and child were well provided for. Due to another move, this time to Lugano in an Italian region of Switzerland, Karl began his schooling needing to master not only his courses but also a new language. When his mother died in 1938, he moved with his father to Schiers in eastern Switzerland, where his courses at the Evangelical College were in German. As a teenager, he became interested in science, politics, and sports. His fascination with radio construction and transmission led to a desire to become an electrical engineer, but his achievements in his chemistry and physics courses swayed a respected teacher to steer him in the direction of physics. With Swiss neutrality during World War II, Karl was able to safely pursue his interests in world affairs, while also developing his skill in alpine skiing. He completed his secondary school education just as the war ended.

After completing his mandatory service in the Swiss army, he enrolled in the Physics and Mathematics Department of the Swiss Federal Institute of Technology (ETH) in Zurich. The American use of atomic bombs to end the war with Japan created a worldwide interest in nuclear physics, and Müller's freshman physics course, taught by Paul Scherrer, was three times its traditional size. Scherrer's approach had a profound effect on Müller, but he was so disappointed in his other physics courses that he almost transferred into electrical engineering. He decided to remain a physics major after taking courses from the Nobel laureate Wolfgang Pauli, who communicated the joy that comes with understanding truths about nature. For his undergraduate research project, Müller measured the transverse electric field in gray tin, a semimetal, when it carried an electric current in a magnetic field perpendicular to the current (the so-called Hall effect). Thus began his lifelong interest in solid-state physics.

After receiving his degree, Müller worked on metallic oxides for a year in industrial research and then resumed his graduate studies. His dissertation, done under the supervision of Georg Busch, centered on the synthesis and properties of strontium titanium oxide. This material had a perovskite structure. Perovskite, or calcium titanium trioxide, is a mineral that was discovered by and named for the nineteenth century Russian count and scientist L. A. Perovski. The basic structure of perovskite has the larger titanium atom at the center of a cube with the smaller calcium atoms at the cube's corners, with the oxygen atoms distributed halfway along the cube's edges. A characteristic of this crystal structure is the octahedral arrangement of the six oxygen atoms around each calcium atom. The perovskites would become a career-long fascination for Müller. While working on his dissertation, he courted and married Ingeborg Marie Louise Winkler. His son Eric was born in the summer of 1957, six months before Müller submitted his thesis.

LIFE'S WORK

After receiving his doctorate in 1958, Müller joined the Battelle Memorial Institute in Geneva, where he managed a group that was studying layered graphite compounds and where his daughter Silvia was born. At Battelle, he deepened his knowledge of nuclear magnetic resonance (NMR) spectroscopy, and in 1962 he began dividing his time between Geneva and Zurich, where he lectured and helped form an NMR group at the University of Zurich. In 1963, this lectureship led to his accepting a position at the International Business Machines (IBM) Research Laboratory in Rüschlikon, near Zurich, which would become the locus of his work for the rest of his career. As a creative researcher, he believed that he needed not only an agile and rational mind, but also a heart that was driven, in his words, by an "internal fire."

During the 1960's, Müller deepened his understanding of the perovskites. IBM's researchers were interested in these compounds because such synthetic perovskites as barium titanium trioxide played pivotal roles in electronic devices. Walter Beringer was a principal collaborator with Müller in his studies of perovskites and perovskite-related compounds. They added ions to certain perovskites and studied how the doped compounds' chemical, electric, and magnetic properties changed. Publication of their results advanced Müller's reputation, leading to his promotion in 1970 to titular professor at the University of Zurich and, in 1972, to his becoming head of the IBM laboratory's physics group.

As a physics student, Müller had learned of the 1911 discovery of superconductivity by the Dutch physicist Heike Kamerlingh Onnes. Having developed techniques for achieving extremely low temperatures, Kamerlingh Onnes was able to liquefy helium, and he found that, at liquid helium temperatures, such metals as mercury exhibited a total loss of electrical resistance. Since Kamerlingh Onnes's work, scientists had found other metals and alloys that superconducted, including an alloy of tin and germanium that superconducted at 23.2 kelvins. In the early 1970's, Müller, stimulated by certain calculations on metallic hydrogen, investigated the possibility of incorporating hydrogen into a perovskite to create a metallic state that might superconduct, but his calculations led him to conclude that the required density of hydrogen within the structure was unattainable.

From 1968 to 1980, Müller spent eighteen months at IBM's Thomas J. Watson Research Center in Yorktown Heights, New York, where he studied ways in which

THE BREAKTHROUGH HIGH-TEMPERATURE SUPERCONDUCTOR

The discovery of a new class of materials that superconducted at a surprisingly high temperature led to such a proliferation of publications that physicists had to reach back to the discovery of nuclear fission to come up with an apt parallel. In the decades before this discovery, searchers for high-temperature superconductors, though not nearly as numerous as they became in the two decades after 1986, were nevertheless numerous enough to study exotic alloys and even complex perovskites. Why, then, did Karl Alexander Müller and J. Georg Bednorz succeed where so many others failed?

In their Nobel lecture, Müller and Bednorz pointed to a series of fortunate circumstances that assisted them in making their breakthrough discovery. Most important, they had the good fortune to meet and decide to collaborate, and their strengths and abilities beautifully complemented each other. Favoring their risky venture was Müller's position as IBM fellow, which permitted him to freely pursue his interests without having to report to company officials. Furthermore, because of their educations, both had an excellent understanding of perovskites. They did run into bad luck when their study of a lanthanum-nickel-oxygen system tested negative for superconductivity, but, by happy accident, they learned of the French work on a barium-lanthanum-copper-oxygen material. They were lucky, too, that the French scientists were interested only in this material's catalytic, not potentially superconductive, property.

When, in January of 1986, Bednorz discovered that a ceramic material he made superconducted at a temperature much higher than any previous material, he and Müller were cautiously optimistic, an optimism that proved fully justified when their discovery ushered in a new era of superconductivity studies. Although Müller and Bednorz did not offer an explanation of the mechanism by which their perovskite superconducted, they did provide clues to other scientists of how future superconductors could be made. Paul Chu and his colleagues in the United States were very successful when they substituted yttrium for lanthanum, and their yttrium-barium-copper-oxygen ceramic was able to superconduct in a liquid nitrogen environment. Within a short time transition, temperatures rose from 35 to more than 120 kelvins. However, *why* these ceramic materials superconducted remained a mystery, and their commercialization has so far been limited to a few restricted markets. Nevertheless, Müller and other scientists in the new field that he helped to create hope that the surprising discovery of high-temperature superconductivity will lead to other, even more fruitful discoveries in the future.

the critical temperature (T_c) at which certain materials superconduct could be increased. He studied the BCS theory, named after its generators, John Bardeen, Leon Cooper, and Robert Schrieffer. To explain superconductivity in certain crystal structures, they used lattice vibrations (phonons) and pairs of electrons with opposite spins (so-called Cooper pairs). The lattice vibrations helped randomize the motion of the electrons, whose Cooper pairs broke apart when the superconducting temperature was reached. Müller's preliminary calculations indicated that superconductivity in perovskite-related materials might be possible.

When, in the fall of 1983, he returned to Zurich, Müller asked J. Georg Bednorz, whose doctoral thesis he had helped to supervise, to collaborate with him in his search for superconductivity in the perovskites. Despite their age difference (more than twenty years), they formed a successful team. Müller was the theoretician who had deep insight into the structures and properties of complex crystal structures, while Bednorz was the skilled experimenter who was able to synthesize these materials and determine their chemical and physical properties. Müller and Bednorz started their search with a lanthanum-nickel-oxygen system, but their nickel-containing perovskites tested negative for superconductivity. A turning point occurred in late 1985 after Bednorz read an article by French chemists describing a compound of barium, lanthanum, copper, and oxygen. Since this material exhibited metallic conductivity over a wide temperature range, it satisfied one of Müller's criteria for superconductive perovskite materials. Bednorz prepared a series of these copper-oxide-containing compounds in which he varied the barium ion concentration. In January, 1986, he found that one of his compounds manifested a sharp drop in resistivity at temperatures as high as 35 kelvins, much higher than any previously studied substance. Because a test of the magnetic properties of their substance was needed to fully establish the true existence of superconductivity, they gave their initial paper, which they submitted in April, a tentative title: "Possible High T_c Superconductivity in the Barium-Lanthanum-Copper-Oxygen System." By the time their paper was published in September, their uncertainty had vanished, since a magnetometer purchased for the IBM laboratory corroborated their discovery of high-temperature superconductivity.

IMPACT

Initially, because many scientists were skeptical that ceramic materials would manifest high-temperature superconductivity, the discovery of Bednorz and Müller was underappreciated by researchers in the field and underreported in general-interest publications. However, in 1987, when physicists in the United States and around the world began reporting that other ceramic materials superconducted at temperatures near 90 kelvins, scientists, entrepreneurs, politicians, and the public became captivated. Müller and Bednorz were honored with the 1987 Nobel Prize in Physics in what some saw as the Nobel Committee's speediest recognition ever of any scientific achievement. As evidence of the great impact of their discovery, Müller and Bednorz received numerous awards and honorary degrees in the decades that followed.

The new superconductors posed challenges for the BCS theory and several new theories that were proposed to account for this surprising discovery. Not one of these theories has gained wide acceptance. Despite the failure to understand *why* these superconductors work in the way they do, other scientists and inventors have tried to find out *how* they can be used in various applications. They have been used in particle accelerators and other devices, but the hope is that superconductors will make energy generation and transmission more efficient and computers faster and more powerful. Their use in magnetic levitation trains will make transportation smoother and safer. Magnetic resonance imaging (MRI) in medicine will become better and less expensive. These predictions, generated due to the euphoria created by the initial discovery of high-temperature superconductivity, have now been replaced by a pragmatic realization that many difficulties will have to be overcome before any utopia fostered by resistance-free electricity is achieved.

—*Robert J. Paradowski*

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See also: John Bardeen; J. Georg Bednorz; Gerd Binnig; Raymond Damadian; Sumio Iijima; Heike Kamerlingh Onnes; Pyotr Leonidovich Kapitsa; Heinrich Rohrer.

KARY B. MULLIS

American biochemist

Mullis conceived and developed the polymerase chain reaction (PCR), which revolutionized the study of the biological and medical sciences. PCR is used in the diagnosis of various infectious and genetic diseases, has been widely used in forensic analysis, and was instrumental in the sequencing of many genomes.

Born: December 28, 1944; Lenoir, North Carolina
Also known as: Kary Banks Mullis (full name)
Primary fields: Biology; chemistry; genetics; medicine and medical technology
Primary invention: Polymerase chain reaction

EARLY LIFE

Kary Banks Mullis was born in Lenoir, North Carolina, to Cecil Banks Mullis and Bernice Alberta Barker Mullis. His family moved to Columbia, South Carolina, when he was five years old. Mullis's mother and father were from rural South Carolina. His father sold institutional furniture, and his mother was active in the community and began selling real estate to put her children through college.

Mullis's interest in science developed very early, when he started to play with electricity at the age of six. His interest in chemistry was stimulated when, at the age of seven, he received a chemistry set as a Christmas present. He attended Dreher High School in Columbia, where he was an excellent student. He was vice president of the student council, president of the Junior Engineering Technical Society (JETS), and a National Merit Scholar. At Dreher, his interest in chemistry was further stimulated by his teacher, who let him experiment in the laboratory in the afternoons. The summer after graduation, he worked for Columbia Organic. In 1962, Mullis entered the Georgia Institute of Technology (Georgia Tech), where he received a B.S. in chemistry in 1966. During the summers while at Georgia Tech, he broadened and increased his knowledge of chemistry while synthesizing chemicals for King's Laboratories.

In 1966, Mullis moved to Berkeley, California, to study for a Ph.D. in biochemistry under Allan Wilson. Soon after arriving in Berkeley, Mullis started to work in the laboratory of Joseph B. Neilands. In Neilands's laboratory, his project focused on schizokinen, a molecule involved with the transport of iron in bacteria. While a second-year graduate student in 1968, he published an article in *Nature* titled "The Cosmological Significance of Time Reversal." He received his Ph.D. in 1972 for "Structure and Organic Synthesis of Microbial Iron Transport Agents."

Mullis remained at Berkeley for a year as a lecturer in biochemistry, and then he moved to Kansas. He eventually accepted a postdoctoral fellowship at the University of Kansas, where he worked in pediatric cardiology specializing in pulmonary vascular physiology.

In 1975, Mullis returned to Berkeley and worked in a coffee shop until 1977, when he accepted a postdoctoral fellowship to work in pharmaceutical chemistry at the University of California, San Francisco.

LIFE'S WORK

In 1979, Mullis accepted a position as a synthetic chemist specializing in the synthesis of oligonucleotides with the DNA (deoxyribonucleic acid) synthesis unit at Cetus Corporation in Emeryville, California. Although Mullis soon made the process of synthesizing oligonucleotides faster and more efficient, with higher yields, he often clashed over methods with Chander Bahl, who headed the DNA synthesis group. In 1981, Tom White, who had recently been appointed head of Recombinant Molecular Research, appointed Mullis head of the DNA synthesis laboratory to replace Bahl.

One evening in the spring of 1983, while driving to his cottage in Mendocino in Northern California, Mullis conceived the polymerase chain reaction (PCR). He had for some time been attempting to develop a technique that could efficiently amplify the beta-globin gene and screen for the presence of the sickle-cell anemia mutation. The project involved the detection of a single base-pair mutation in the sickle-cell beta-globin gene by seeing if it could be digested with a specific restriction endonuclease. Normal beta-globin DNA would not be digested. Since the technique was hampered by the small amounts of beta-globin DNA available, Mullis was attempting to design a method to amplify beta-globin DNA in order to make the beta-globin project better and the assay more reliable. He realized that if he used two oligonucleotides that bound to opposite sides of sickle-cell beta-globin DNA, the oligonucleotides could be extended by DNA polymerase and make a copy of the sickle-cell beta-globin DNA contained between the two oligonucleotides, resulting in twice the amount of sickle-cell beta-globin DNA. If other rounds were carried out, the increase in the target DNA would be exponential. Although his colleagues at Cetus were not very encouraging of his amplification concept, he made a presentation about the potential method at an August, 1983, Cetus meeting.

Mullis did his first PCR experiment on September 8, 1983. Although his initial attempts to amplify a specific target DNA failed, by June, 1984, he had achieved some success with both plasmid and human DNA targets. By the spring of 1985, DNA amplification by PCR had been perfected by Mullis and his assistant, Fred Faloona, working with Cetus laboratory technicians, namely Stephen Scharf and Randall K. Saiki. Cetus applied for a patent for the PCR procedure on March 28, 1985. Although Mullis's name was on the patent application, all rights were held by Cetus. In the spring of 1986, Mullis received a $10,000 bonus for his invention.

THE POLYMERASE CHAIN REACTION

Kary B. Mullis not only conceived the concept of the polymerase chain reaction (PCR) but also was instrumental in developing it into a technique that revolutionized the study of genetics, molecular biology, medicine, and forensic science. PCR has three steps: The first step involves denaturation, during which the double-stranded DNA sample is heated to 92°-96° Celsius for about thirty seconds, causing the two DNA strands to separate. The second step involves annealing of single-stranded nucleotide chains, called primers, to opposite ends of the target DNA as the sample is cooled to 55°-65° Celsius for about thirty seconds. The third step involves the extension of those primers by DNA polymerase as the temperature is raised to about 72° Celsius for about one minute. The result is that after one cycle of denaturation, annealing of primers, and extension, one double-stranded target DNA has been replicated into two double-stranded DNA molecules. After thirty cycles of PCR, which takes about three hours, the target DNA is amplified to more than one billion target molecules. The amplified target DNA can easily be detected by electrophoresis. PCR has been fully automated with the use of thermostable DNA polymerases and the development of thermocyclers that can be programmed to incubate the PCR reaction for specific times at specific temperatures.

PCR has widespread application in science. It was instrumental in allowing for DNAs to be amplified, providing enough DNA for sequencing the human and other genomes. PCR is also used extensively in medicine for the rapid diagnosis and screening of genetic diseases such as sickle-cell anemia and cystic fibrosis in fetuses, newborns, and adults, and the detection of pathogenic bacteria, viruses, and parasites such as those that cause acquired immunodeficiency syndrome (AIDS), Lyme disease, pneumonia, and a variety of sexually transmitted diseases. PCR is used to detect the presence of genes that may make one susceptible to certain diseases such as coronary artery disease and cancer. PCR is used extensively by forensic scientists for DNA profiling (formerly referred to as DNA fingerprinting) for use in crime scene analysis, human identification, and paternity testing. Modern adaptations of PCR called real-time PCR and reverse transcriptase PCR (RT-PCR) use fluorescent detection of the amplification products and allow molecular biologists to quantify DNA. By using RT-PCR, molecular biologists study the expression and regulation of specific genes under various conditions. Portable real-time thermocyclers that can be taken into the field allow for the rapid detection of several highly pathogenic organisms, such as *Bacillus anthracis* (anthrax), that could potentially be exploited by terrorists.

The first paper—which was coauthored—describing the applications of PCR, "Enzymatic Amplification of Beta-Globin Genomic Sequences and Restriction Site Analysis for Diagnosis of Sickle Cell Anemia," was published in *Science* on December 20, 1985. Mullis presented his concept of PCR at the May, 1986, Cold Spring Harbor Laboratory Symposium on the Molecular Biology of *Homo sapiens*. Later that year, he published on the concept of PCR and its applications in the *Cold Spring Harbor Symposia on Quantitative Biology*, and in 1987 he published in *Methods in Enzymology* more details of PCR conditions in "Specific Synthesis of DNA in Vitro via a Polymerase-Catalyzed Chain Reaction," after having been previously rejected by *Science* and *Nature*. The first PCR patents were awarded to Cetus in June, 1987. Cetus sold the patent rights to PCR to F. Hoffmann-La Roche in 1991 for $300 million.

In 1986, Mullis left Cetus and joined Xytronyx, a small biotechnology company in San Diego, California, as director of molecular biology. There Mullis worked on DNA technology and photochemistry. He left Xytronyx in 1988 to serve as a consultant for several biotechnology companies.

Mullis has developed an idea that could have significant impact in the field of immunology. He has been working on a method that uses chemical linkers to change the specificity of an antibody from its normal target to a different target. Since humans are naturally immune to many antigens, a linker molecule could be synthesized that would potentially bind to the human antibody at one end and a virus at the other end, resulting in the inactivation of the virus. In this way, antibodies that would normally bind to one antigen could theoretically be diverted to bind to a second antigen. The linker concept has been applied successfully to rodents. Mullis started a small company, Altermune, to coordinate his work on immunology.

Mullis served as Distinguished Researcher at Children's Hospital Institute in Oakland, California. He sat on the board of directors of several companies and organizations. Besides his autobiography, *Dancing Naked in the Mind Field* (1998), he is the author of several scientific publications. He is also the author of several patents, including PCR and one for a plastic that changes color in response to ultraviolet light. He is the recipient of several awards, including the William Allan Memorial Award of the American Society of Human Genetics (1990), the Gairdner Foundation International Award (1991), the National Biotechnology Award (1991), the California Scientist of the Year Award (1992), and the Thomas A. Edison Award and the Japan Prize (both 1993). Mullis won the 1993 Nobel Prize in Chemistry "for contributions to the developments of methods within DNA-based chemistry" and "for his invention of the polymerase chain reaction (PCR) method." Mullis shared the Nobel Prize with Michael Smith. Mullis was a 1998 inductee of the National Inventors Hall of Fame.

IMPACT

PCR has multiple applications and has had a profound impact on the fields of molecular biology, genetics, medicine, biotechnology, and forensic science. It is a revolutionary technology that precisely copies DNA. In a matter of two or three hours, one DNA molecule can be amplified to billions of copies, making analysis of specific DNA targets possible. The use of PCR technology has accelerated the analysis of the structure and function of genes and the sequencing of several genomes, including that of humans. The technology has been employed to screen and diagnose various viral and bacterial infectious diseases such as HIV/AIDS, tuberculosis, and staphylococcus. In addition, PCR has been used for the prenatal, neonatal, and carrier testing of numerous genetic diseases as well as for sex determination using prenatal cells. PCR has led to the development and employment of DNA-testing methodologies for forensic applications, including human DNA profiling and identification.

—*Charles L. Vigue*

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See also: Marie Anne Victoire Boivin; Robert Charles Gallo; Donald A. Glaser; Mary-Claire King; Selman Abraham Waksman.

WILLIAM MURDOCK

Scottish engineer

Murdock's creative genius brought developments in areas as diverse as steam engine design and chemical dyes and led him to pioneer the use of coal gas for commercial and domestic lighting.

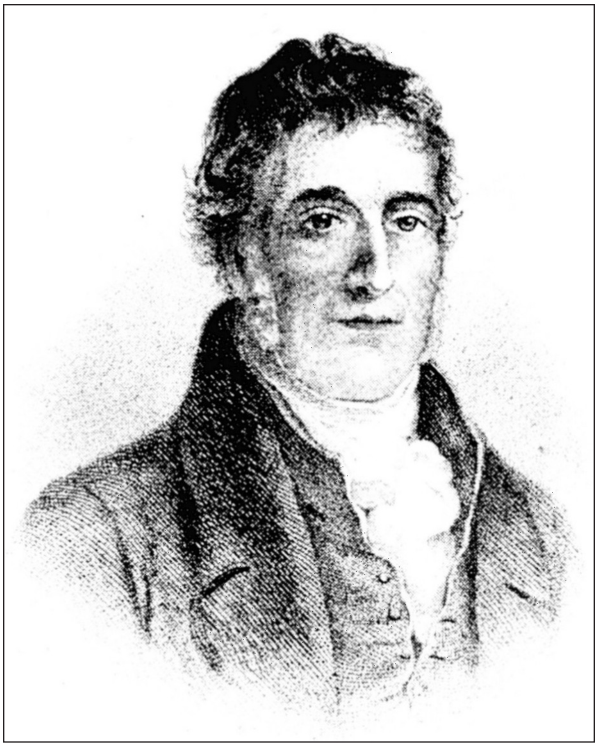
Born: August 21, 1754; Bellow Mill, near Old Cumnock, Ayrshire, Scotland
Died: November 15, 1839; Birmingham, England
Also known as: William Murdoch
Primary field: Civil engineering
Primary inventions: Improved steam engine; coal gas lighting

EARLY LIFE

William Murdock was born near Old Cumnock in Ayrshire, Scotland, on August 21, 1754, the oldest surviving son of Anna and John Murdock's seven children. His father was a miller and wheelwright, from a family that included many other respected technicians, engineers, and clockmakers. John had a reputation for exceptional intelligence, skill, and inventiveness, and young William worked with him on many projects at the mill, on the family farm, even designing and constructing bridges, acquiring great expertise and technical knowledge. John is also said to have invented a "wooden horse," a tricycle predating pedal bicycles by several decades, and young William would certainly have ridden this in his childhood.

William spent many boyhood hours in a small riverbank cave beside the mill and here began simple experiments with steam; he may even have started to investigate producing light by burning the gas produced by heating coal in a kettle. He would certainly have been familiar with the sight of coal burning in the family fireplace on winter evenings, which had the unusual property of hissing and spitting as it emitted spurts of gas that burned brightly at its surface.

William, however, was ambitious to make a name for himself. Through his father's business connections, he heard about the inventions of the great engineer James Watt and became determined to work at the famous Soho Manufactory in Birmingham, England, where Watt was in partnership with Matthew Boulton. Accordingly, in August, 1777, at the age of twenty-three, William left his family to walk the three hundred miles to Birmingham. Boulton was immediately impressed by the young engineer and found him a place at the foundry.



William Murdock. (Library of Congress)

At this time, much of the firm's work was in steam engines, especially for pumping water from mines. Boulton and Watt jointly owned the patent for Watt's separate-condenser engine. Murdock quickly learned the business: By the following year, he was much sought-after in the pattern shop, and within two years (March, 1779) was being sent to manage the erection of engines around the country. On his first such solo job, he rearranged the gears of Watt's engine, greatly improving its performance. Although Watt was very protective of his design, he admired Murdock's ingenuity, and the young mechanic grew in his esteem and trust.

Coal Gas Lighting

When coal is heated in a process that is essentially a destructive distillation, a significant fraction of the coal may be driven off as gas. Depending on the type of coal—its geological source and mineralogical history—the gas evolved will contain principally hydrogen, carbon monoxide, and methane, each in greater or lesser quantities. All three of these gases are highly flammable, burn very efficiently in air, and produce both heat and light as they do so. Even with his relatively primitive apparatus, William Murdock was able to collect and purify this mixture of gases; he introduced quicklime as the best solution for removing the sulfurous gases that contaminated the fuel—their unpleasant odor was one of the main initial drawbacks of using coal gas. His experiments also determined the best way of burning the gas, and what types of apertures would be most effective, ultimately leading to the widespread application of this relatively simple principle to domestic and commercial lighting.

Prior to Murdock's work, oil and tallow were the main fuels used for lighting. They had the great disadvantage that they were considerably less efficient, principally because they did not burn very cleanly. Instead, they produced significant amounts of soot as they burned, and they produced only a very poor quality of light. Coal gas lighting, on the other hand, gave a much brighter and steadier flame, was much cleaner, and was up to 50 percent cheaper. Despite initial skepticism and resistance to change, therefore, Murdock's gaslight was destined to spread rapidly.

Just as the Industrial Revolution was bringing advances and improvements in living standards, gas lighting played its own crucial part. Shops could remain open later, and the lighting of streets made them much safer. At home, people were able to read more easily in this bright new light—and the poor in particular had new worlds opened up to them as newspaper circulation increased. Community gatherings on dark evenings became possible. Profound social changes took place ahead of the twentieth century and the dawn of electric light. There can be no doubt that Murdock's gaslight wrought a change as great as Thomas Alva Edison's light bulb.

Life's Work

Later in 1779, Murdock was sent as manager of the firm's interests to Cornwall in southwest England, which would be his home for almost twenty years. Many of the local copper and tin mines had installed Boulton and Watt pumping engines, and Murdock was to keep them running smoothly. Many times he would modify an engine's design to enhance its performance. Murdock worked so diligently, with such consummate skill, and often without sleep, that he became more valued by his employers, and he achieved great popularity with the mine owners—who, above all, loathed production stoppages.

Murdock also worked on many other projects while in Cornwall. Ways were sought whereby Watt's steam engine could produce rotary motion for the moving machinery of the country's mills, a central part of the Industrial Revolution. Boulton and Watt patented five different methods for generating rotary motion, of which the sun-and-planet gear invented by Murdock was the most widely used. It was patented in February, 1782, less than five years after he joined the firm.

Around the same time, Murdock was beginning to speculate whether the steam engine could also be used to produce locomotion. He already knew, from riding his father's tricycle years earlier, that machines could be made to transport people. However, up to then the wheels were always turned by the strength of a person or an animal. Turning wheels using a machine required a unique mind to recognize the possibility and a talented engineer to make the idea a reality. Murdock combined both of these qualities, and by 1784 he had a working model drawing a small wagon around his living room in Redruth, Cornwall. This was the first working steam locomotive in Great Britain: Nicolas-Joseph Cugnot in France had demonstrated such a vehicle in 1769, but his experiments were curtailed by accidents and its inefficient design.

Unfortunately, neither Boulton nor Watt was enthusiastic about Murdock's "steam carriage," concerned that it would distract him from his other duties within the firm. They believed that all their energies—and Murdock's—should be directed toward maintaining the market superiority of Watt's engine, and they were busy with litigation over steam engine patent infringements. As a result, a great opportunity was missed, and the company failed to benefit from one of Murdock's greatest achievements. It was left to competitors such as Richard Trevithick to produce their own steam locomotives around the beginning of the nineteenth century.

Murdock may have been bitter and puzzled by his employers' behavior, but he remained loyal to them and would soon turn his attentions to fresh innovations. It is a remarkable testament to his strength of character that his professional relationships remained solid, especially as these were also years of great personal upheaval. He had married Anne Paynter, daughter of a mine captain, in 1785, and the following year experienced the loss of twins. Two more sons were born in consecutive years, but he then endured the tragedy of his wife's death in 1788.

Within a few years, Murdock embarked upon new challenges. People knew that gases were given off when coal was heated, and that the gases could be ignited, but Murdock realized the potential of gaslight. He launched a series of experiments at home in Redruth, examining the combustion properties of various materials, comparing the gases produced by coal from different coalfields, and devising means of purifying the gases. He investigated air-gas ratios and the sizes and shapes of apertures giving the most efficient combustion and the best quality of light. Coal gas proved more economical, and provided better illumination, than either oil or tallow, which then were the predominant lighting fuels.

Murdock equipped his house for gas lighting around 1792, the gas being conveyed along pipes from his workshop where coal was heated in a retort. He also devised a portable gas lantern consisting of a gas-filled bladder, with a pipe attached, from which the gas jet could be lit and light his way on dark nights. Bizarrely, Murdock's employers again appeared somewhat indifferent to this momentous advance. The company did not patent the concept, and others would profit from it. However, Murdock was made manager of the new Soho works in 1798 and continued to work on gas lighting. The Soho factory was publicly illuminated in March, 1802, and other premises around the country had gas lighting installed over the next few years. Gas lighting became widespread in cities around the country within two decades, and Baltimore was the first major U.S. city lit by gas in 1817.

The Royal Society of London awarded Murdock the Rumford Medal in 1808 for his achievements. He continued to work on a variety of projects, retiring in his seventy-sixth year. He and Watt remained great friends, and Watt's death in 1819 caused Murdock great grief. In his last years, his own health began to fail, but he remained active until the death of one of his sons, when he deteriorated and died on November 15, 1839, aged eighty-five.

IMPACT

Murdock came from a family of inventors, so it is no surprise that even as a young man his imagination was working on simple solutions to complex problems. Visitors to the Soho factory observed many of his innovations and special machine tools that "had his genius stamped on them." Murdock contributed significantly to the improvement of the steam engine and steam power, devising notably the oscillating cylinder engine and the bell-crank engine, which was used on steamboats. He also introduced several advancements in rotary motion, including the sun-and-planet gear and the worm wheel.

Murdock also had a fascination with compressed air, steam, and pneumatic devices, and he invented a type of stirrup pump, pneumatic lifting gear, and even a pneumatic doorbell. He also created a system of transmitting letters through pipes using compressed air (used in drive-up banking facilities), and a high-pressure steam gun whose principle was later used to launch planes from aircraft carriers.

Murdock is best remembered for introducing gas lighting, and its attendant benefits, but chemical innovations also came from this. Some of the by-products of coal-gas production became very profitable aspects of gas works business: Coke and coal tar were especially valuable, and some of the other chemicals isolated became aniline dyes—the subject of one of Murdock's own patents (1791). He is also credited with the adventitious discovery of iron cement, and he developed a technique to cheaply produce isinglass for beer clarification.

Murdock was not motivated by fame and fortune; he was simply driven by his work and was content to observe the great benefits that others would derive from his singular achievements. His loyalty to the company even in very difficult circumstances speaks to his remarkable character, and the breadth of his inventiveness belies his extraordinary mind.

—Thomas D. McGrath

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See also: Nicolas-Joseph Cugnot; Thomas Alva Edison; Thomas Newcomen; Richard Trevithick; James Watt.

PIETER VAN MUSSCHENBROEK

Dutch physicist and mathematician

An adherent of Isaac Newton's experimental method, Musschenbroek is usually given credit for invention of the Leiden jar, the first device to store electricity generated by a friction machine.

Born: March 14, 1692; Leiden, the Netherlands
Died: September 19, 1761; Leiden, the Netherlands
Primary field: Physics
Primary invention: Leiden jar

EARLY LIFE

Pieter van Musschenbroek (PEE-tur vahn MOO-shehn-brook) was born in 1692 to Johan Joosten van Musschenbroek and Maria van der Straaten. The family history played a significant role in the development of Musschenbroek's career. In the late sixteenth century, the Protestant Musschenbroek family had fled from the Southern Netherlands to Leiden to escape persecution by the Spanish. In Leiden, the family established a brass foundry, producing items such as lamps and weather vanes and gaining a fine reputation for the construction of scientific instruments during the seventeenth century. From 1707 to 1749, Pieter's older brother, Jan, ran the business, where as a boy Pieter helped in the workshop. The Musschenbroek workshop contained a library of more than eight hundred scientific works, including books on physics and electricity, with scientists themselves frequenting the establishment.

Pieter van Musschenbroek studied classical and modern European languages at the Leiden Latin School. In 1708, he matriculated at the University of Leiden, where he earned a doctoral degree in medicine in 1715. In 1717, he traveled to England, where he met Isaac Newton and other scientists in the Newtonian circle. In England, he also attended John Theophilus Desaguliers's lectures on experimental physics. In 1719, he received a second doctorate, in philosophy, with a concentration in physics, at Leiden. There, he studied with Willem Jacob 's Gravesande, author of the first comprehensive book on physics and frequent client of Jan van Musschenbroek.

LIFE'S WORK

In 1719, Musschenbroek took a position as professor of mathematics and philosophy at the University of Duisburg; in 1721, he was also appointed professor of medicine. He taught these subjects from 1723 to 1739, and in 1732 he was promoted to the chair of astronomy at the University of Utrecht.

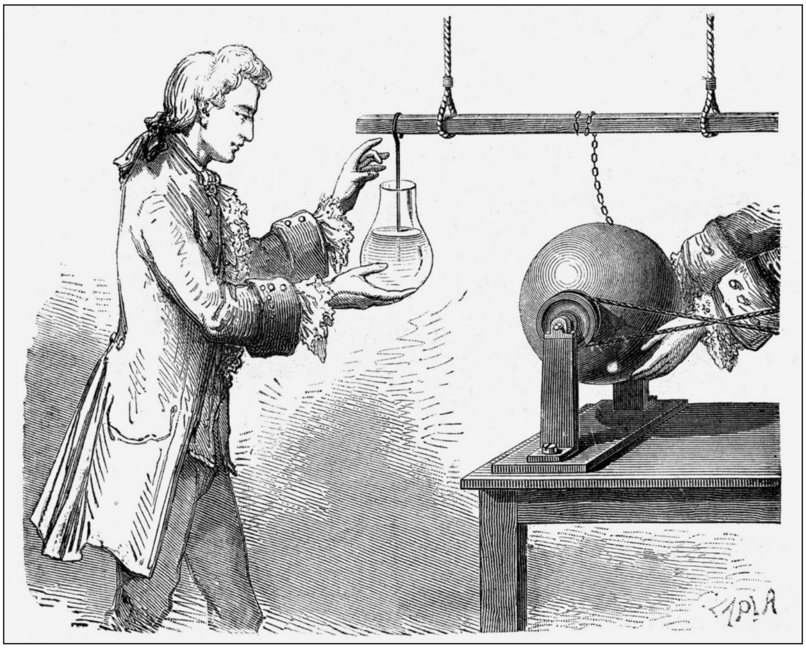
An understanding of Musschenbroek's invention of the Leiden jar requires a brief account of the state of science at that time. Two schools of thought concerning the study of natural phenomena existed then. In setting down the ideas of rationalism, René Descartes had argued that knowledge was found in reason and deduced from first principles. In contrast, Newton asserted that science was grounded in observation and experiment, with the results expressed in terms of mathematics.

While Herman Boerhaave was the first to advocate

Newton's method in the Netherlands in 1715, Musschenbroek, along with 's Gravesande, facilitated the introduction of the Newtonian experimental method in the Netherlands. One of Musschenbroek's earliest works, *Oratio de certa methodo philosophiae experimentalis* (discourse on the most certain method in experimental philosophy), a series of lectures published in 1723, supported the Newtonian method. In 1725, he attacked Cartesian physics directly in a letter to the *Philosophical Transactions of the Royal Society* in London.

A lifetime of teaching and performing experiments reflected Musschenbroek's acceptance of the philosophy of Newton and led to the publication of several important textbooks during his tenure at Utrecht. Among his works is a summary of his lectures, *Epitome elementorum physico-mathematicorum, conscripta in usus academicos* (1726), republished in 1741 under the title *Elementa physicae, conscriptae in usus academicos*. It appeared in an English translation in 1744 as *Elements of Natural Philosophy Chiefly Intended for the Use of Students in Universities*, and in a German translation in 1747. Another work, *Oratio de methodo instituendi experimenta physica* (1730; discourse on the method for performing physical experiments), became a standard textbook. In 1736, he published *Beginselen der natuurkunde* (principles of natural philosophy) in Dutch, translated into French as *Essai de physique*. Although these early works did not contain much about the study of electricity, a science still very much in its infancy, the experimental techniques described in them enabled him to discover a way to store electricity.

Through the efforts of Boerhaave in medicine and chemistry and 's Gravesande in physics, the University of Leiden had gained preeminence in the Newtonian experimental method. After the university's last Cartesian mathematics teacher died in 1739, Musschenbroek accepted an offer to succeed him, and when 's Gravesande died in 1742, Musschenbroek assumed his teaching position in experimental physics. During the early years at Leiden, Musschenbroek became interested in the phenomena of electricity and performed or repeated all the known experiments on it in less than a month. At the end of 1745 and beginning of 1746, Musschenbroek, with Jean Allamand, an assistant from the university, and Andreas Cunaeus, a lawyer who enjoyed visiting the laboratory, discovered that a jar filled with water stored static electricity generated by a friction machine. The entire quantity of electricity discharged when a person touched the wire connecting the source of the electricity and water in the jar. In January, 1746, after confirming the phenomenon, Musschenbroek wrote a letter in Latin to René Réaumur, his contact at the Paris Academy of Sciences, who in turn reproduced the experiment. The popularizer of science Jean-Antoine (Abbé) Nollet translated the letter and published the first drawing of the experiment with the "Leiden jar," as he called the device in his 1746 book *Essai sur l'éléctricité des corps* (essay on the electricity of bodies).



Pieter van Musschenbroek with the Leiden jar, a primitive capacitor. Wood engraving, nineteenth century. (The Granger Collection, New York)

At Leiden, Musschenbroek continued to produce new editions of his textbooks. A final expansion of the *Epitome* resulted in a two-volume work, *Introductio ad philosophiam naturalem* (introduction to natural philosophy), which appeared posthumously in 1762. He taught at the University of Leiden until his death on September 19, 1761. He was buried with his second wife.

IMPACT

Although the historical significance of Musschenbroek's work rests more

MUSSCHENBROEK'S LEIDEN JAR

During Pieter van Musschenbroek's time, the only form of electricity known was static electricity. The word "electricity" derives from *elektron*, the Greek word for "amber." Ancient Greeks were aware of static electricity from observing that amber, when rubbed with a woolen cloth, attracted bits of fiber and other light objects. Friction machines invented in the seventeenth century generated static electricity by rubbing a rotating object such as a sulfur ball or glass globe. Francis Hauksbee advanced the theory that minuscule particles of a subtle fluid constituted electricity.

While electricity could be generated, no way to store it existed before the Leiden jar. Ewald Georg von Kleist most likely developed the jar condenser several months before Musschenbroek. However, von Kleist shared his experiment with only a few people, and, as his instructions were inadequate, his correspondents failed to reproduce the results.

Unaware of von Kleist's work, Musschenbroek conducted experiments inspired by the works of Andreas Gordon, who had developed a technique to electrify water, and Georg Matthias Bose, who had attempted to extract electricity from water charged in a glass container. According to the understanding at that time, the electrical effluvia flowed into the water and were stored there. After Musschenbroek repeated the experiment, he clearly described the arrangement. The experiment was set up in this manner: An iron tube suspended by silk cords connected to the friction machine on one end and on the other to a brass wire or nail that passed through a stopper into water inside a glass container. The glass rested on an insulated surface, a practice instituted by Charles François de Cisternay Du Fay. Alone one day, Musschenbroek's student Andreas Cunaeus held the glass in his hand while generating the electricity and received a shock when he attempted to remove the wire. Musschenbroek repeated the experiments many times and realized that the key to obtaining the effect was to ground the jar by holding it in the hand and not to insulate the glass container. In this manner, Musschenbroek and his associates invented a primitive capacitor, a device that stores electrical energy.

Other experimenters made improvements to the Leiden jar. Jean-Antoine Nollet, for example, found that mercury or any liquid other than an oil could be used. Others discovered that the discharge could be increased by using larger glass vessels or by lining the glass inside and outside with metal foil. The foil-lined jar became the standard construction, with the wire or nail connected to inside the foil, sometimes with a small chain. Benjamin Franklin connected several jars together into what he termed a "battery" that gave off a large shock he analogized to a battery of cannons.

Franklin also discovered that the charge was not stored in the liquid and reasoned that it was stored in the glass. More precisely, when a Leiden jar connects with an electrical source, the interior surface acquires a positive charge from the conductors—that is, from either the water or the foil—and the exterior a negative charge. The glass container serves as insulator between the differently charged surfaces. Touching the wire while holding the jar in the hand completes an electrical circuit and results in the shock.

on his promotion of the experimental method and the publication of textbooks than on his role as an inventor, the Leiden jar was the most important electrical invention of the eighteenth century. It spread quickly from the Netherlands to the major countries of Europe and England, as well as to America, and opened a new era in the study of static electricity. Immediately, it became a source of salon demonstrations. Nollet, for example, entertained the king of France with a circle of 180 guards who formed a ring by holding hands, while the first man held the Leiden jar and the last touched the wire. As the electricity discharged, all the men reportedly jumped simultaneously.

The Leiden jar also served as an instrument for serious scientific research. Benjamin Franklin undertook experiments using it in his storied kite experiment, in which the key, wrapped in silk, served to charge the Leiden jar with electricity from the lightning bolt that traveled down the kite's string. This experiment proved that lightning and static electricity were the same phenomenon.

The invention of the Leiden jar inspired research on electricity as a biological phenomenon. Researchers studied the electric eel. Physicians and medical quacks used Leiden jar electricity in attempts to treat paralysis and a multitude of medical disorders. By the end of the century, Luigi Galvani had performed a series of experiments to demonstrate his idea that the nerve impulses were conveyed by electricity, not by fluids as previously thought. He believed that the muscles of frogs' legs acted like a Leiden jar.

As time progressed, the principles of the Leiden jar led to the invention of smaller capacitors that are essential in the operation of electrical devices such as the telegraph, radio, and other communications devices.

—*Kristen L. Zacharias*

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See also: Benjamin Franklin; Ewald Georg von Kleist; Sir Isaac Newton.

SHUJI NAKAMURA

Japanese American electrical engineer

Nakamura's invention of bright blue light-emitting diodes (LEDs) opened up the full light spectrum for this source of solid-state, energy-efficient lighting, including the creation of white LED light. His invention of the blue laser diode paved the way for great advances in optical data storage, while his ultraviolet LED provided inexpensive water purification.

Born: May 22, 1954; Oku, Ehime Prefecture, Japan
Primary fields: Electronics and electrical engineering; physics
Primary invention: Blue light-emitting diodes (LEDs)

EARLY LIFE

Shuji Nakamura (shoo-jee nah-kah-moo-rah) was born on May 22, 1954, in the tiny fishing village of Oku on Sadamisaki Peninsula in Ehime Prefecture, Shikoku. His father, Tomokichi Nakamura, worked as a maintenance man for Shikoku Electrical Power and his mother's parents were farmers. He had an older brother and sister, and a younger sister. His father taught him to make movable wooden toys, such as bamboo propellers, and the young Nakamura showed interest and skill. In 1961, when Nakamura was seven years old, his family moved inland to the small town of Ozu.

In high school, Nakamura enjoyed playing volleyball and excelled in math and science, yet he despised the rote learning required to pass the entrance exams to Japan's best universities. In 1973, at age nineteen, he went to local Tokushima University, where he was inspired by semiconductor technology. He earned his degree in electrical engineering in 1975 and decided on graduate work. His thesis adviser, Professor Osamu Tada, strongly emphasized experimental research, which suited Nakamura in his master's studies on the conductivity of barium titanium oxide.

On February 22, 1978, Nakamura married the daughter of a Tokushima banker. The couple's first daughter, Hitomi, was born in August, 1978. To be a married student with a child was very unusual in Japan at this time.

After receiving his master of science degree in electrical engineering in 1979, Nakamura began looking for a job. Faced with the prospects of becoming a typical anonymous salary man researcher at the large company Kyocera in Kyoto, Nakamura asked Professor Tada to find him a job on Shikoku. Tada introduced Nakamura to Nobuo Ogawa, president of Nichia Chemical Industries, a small company a few miles south of Tokushima in the semirural town of Anan. Determined to seize this opportunity, Nakamura secured employment with Nichia in April, 1979.

LIFE'S WORK

Nichia specialized in making phosphors for television cathode-ray tubes and fluorescent lamps. Nakamura was asked to invent ways to manufacture base products needed to make red and infrared light-emitting diodes (LEDs), which were invented in 1962 and in high demand by the early 1980's. Nakamura essentially worked alone, and by 1982 he had successfully developed crystals of gallium phosphide. Unfortunately, his crystals were a commercial failure because customers preferred the products of well-known Japanese companies. His next two successful inventions were also commercial failures because of the Japanese preference for brand names. In desperation, Nakamura decided on entirely new research.

Nakamura's greatest challenge was to invent commercially viable bright blue LEDs. Scientists had tried but not succeeded. Late in 1987, Nakamura took the bold step of asking Nichia's president, Ogawa, for permission to pursue the development of a blue LED. Nakamura asked for some $3 million, or about 2 percent of Nichia's sales. Surprisingly, Ogawa granted this.

To learn how to grow the material for a blue LED in a metal-organic chemical vapor deposition reactor (MOCVD), Nakamura was sent on a one-year research sabbatical to the University of Florida in Gainesville in 1988-1989. There, he ended up assembling his own MOCVD. As always in his life as a scientist, Nakamura worked twelve-hour days, from 7:00 A.M. to 7:00 P.M., seven days a week, only taking brief holidays.

Returning to Japan, Nakamura made the crucial decision to focus on gallium nitride (GaN) as source material for his blue LED. He assembled his own MOCVD reactor at Nichia's research lab in Anan and began experiments to grow ultrathin GaN films. At a conference in Japan in 1989, he learned that Isamu Akasaki had developed a dim blue LED based on GaN, but one of inferior quality and too difficult to make commercially.

In early 1990, Nichia's new president, Eiji Ogawa, son-in-law of Nobuo Ogawa, suddenly ordered Nakamura to stop his GaN research, but Nakamura clandestinely refused. In October, 1990, Nakamura invented his two-flow MOCVD reactor, in which hot gases were piped in at right angles to each other, preventing gas convection from interfering with the growing of GaN films. He secretly published a scientific paper about his invention that he also filed as a patent for Nichia. By the end of 1990, Nakamura had produced the purest high-quality gallium nitride ever. He called his invention the most memorable moment in his research life.

On November 12, 1993, in Tokyo, Shuji Nakamura announced Nichia's first bright blue LED. He had won the race for his company, which subsequently prospered immensely. In 1994, he was rewarded a Ph.D. in electrical engineering from Tokushima University. In May, 1994, Nakamura invented a blue-green LED, in 1995 an emerald-green LED, and in September, 1995, a quantum well-based blue-green LED. Nakamura became a star at international scientific conferences. In 1996, he presented his prototype blue laser diode, improved in 1997 and commercially shipped in 1999.

Eiji Ogawa treated Nakamura shabbily and rewarded him poorly. Nakamura's lifetime earnings were close to that of his wife, Hiroko, a kindergarten teacher. In mid-1999, Nakamura consulted with his family, and they agreed for him to become a professor in the United States. On December 27, 1999, Nakamura resigned from Nichia. Because he refused to sign an agreement not to file any patents for three years, Nichia withheld his retirement benefits. On February 19, 2000, Nakamura became a professor in the Materials Department of the College of Engineering at the University of California, Santa Barbara (UCSB).

Nichia sued Nakamura on December 27, 2000, for leaking its trade secrets to Cree, an LED manufacturer. In early 2001, Nakamura became Cree Professor of Solid State Lighting and Display at UCSB. On August 23, 2001, Nakamura sued Nichia for $16.5 million, deemed his share of Nichia's sales of $11.4 billion from Nakamura's patents. In September, 2002, a Tokyo court agreed that Nichia owed Nakamura fair compensation. Nichia had paid him only $180. In October, 2002, Nichia's suit against Nakamura was dismissed. On January 30, 2004, Nakamura won a landmark $190 million award against Nichia, who appealed immediately. On January 11, 2005, Nakamura and Nichia settled for about $8 million, most of which went to pay Nakamura's legal bills and taxes.

At UCSB, Nakamura continued research into blue lasers capable of effec-

THE BLUE LIGHT-EMITTING DIODE (LED)

Ever since Nick Holonyak, Jr., invented the first red light-emitting diode in 1962, the race was on to discover a way to make blue light-emitting diodes of a sufficient luminosity and in a commercially viable way. The challenge was to find a suitable compound semiconductor material that could be made to emit blue light. Among other candidates, gallium nitride (GaN) showed promise. In the United States in 1971 and 1972, Jacques Pankove and Herb Maruska created some experimental, but dim, blue LEDs with gallium nitride. In Japan in 1973, Isamu Akasaki developed a dim blue gallium nitride LED, which was improved with the help of his assistant, Hiroshi Amano, at Nagoya University in 1986, but which failed to be commercially viable.

Shuji Nakamura decided to join the race for the first bright blue LED in 1987. His invention of a two-flow metal-organic chemical vapor deposition reactor (MOCVD) provided him the means to grow high-quality gallium nitride of an unmatched quality as a compound semiconductor for blue LEDs. Next, he needed to grow a GaN layer with excess electrons, called a negative type. What had been missing from other experiments was a GaN layer with a deficiency of electrons, called a positive type. Light is emitted by semiconductors if excess electrons from one layer are made to migrate to another layer that lacks electrons, thereby creating the desired light.

In July, 1991, Nakamura created a positive-type GaN layer. This enabled him to make his first blue LED. It lived for one thousand hours but was still too dim. Using a new thermal annealing technique in his reactor, Nakamura created high-quality positive-type GaN in December, 1991. By June, 1992, Nakamura succeeded in growing indium gallium nitride (InGaN) as a third layer, or quantum well, between the negatively and positively charged GaN layers to exponentially increase the brightness of his LED. In September, he created the double heterostructure of his GaN crystal films, and in December his first LED shone with a brilliant blue color. In November, 1993, he announced his invention to a stunned world.

The invention of the bright blue LED made it possible to create all colors of light from LEDs and found immediate applications in large, flat television screens and traffic lights. Computer screens followed, as well as experimental lamps and lighting fixtures. It became conceivable that based on Nakamura's invention, the conventional incandescent light bulb would be replaced in the twenty-first century by a much more energy-efficient alternative.

tive data storage, new white LEDs for everyday lighting, and ultraviolet LEDs for water purification. On June 15, 2006, he was awarded Finland's Millennium Technology Prize of $1.4 million, part of which he donated to LED research projects in developing countries. On June 4, 2008, Nakamura was honored with Spain's Prince of Asturias Award for Technical and Scientific Research.

IMPACT

Nakamura's invention of the bright blue LED demonstrated that even in the late twentieth century, a single inventor, when working in a supportive environment, could come up with novel, groundbreaking results, outpacing well-funded and well-staffed research teams. Nakamura's bright blue LED meant that for the first time, LEDs covered the full spectrum of the visible light. Thus, LEDs could be used for a broad range of applications requiring more than just red, yellow, or amber light. Immediate uses of his LED technology included large outdoor television screens and traffic lights.

Nakamura's blue laser diode ushered in the next generation of optical storage devices. Because of their shorter wavelength, blue lasers can read 4.6 times more information stored on a compact disc (CD), for example, than red lasers. This meant longer playing times of CDs.

Nakamura's inventions in blue light LEDs and blue lasers also opened up a potentially vast technological advance in lighting, with much more energy-efficient, inexpensive, and long-lasting LEDs replacing the conventional incandescent light bulb or fluorescent tube for all white light needs, from homes to workplaces to consumer entertainment goods. LED lighting based on Nakamura's groundbreaking inventions may save technologically advanced countries billions of dollars in lower energy costs and by lowering the need to build new power plants. Especially important for developing countries, Nakamura's ultraviolet LED can be used as a safe, effective, and affordable means of water purification.

Nakamura's successful countersuit against Nichia changed the way Japanese researchers and scientists are rewarded by the companies that employ them. With Japanese companies legally forced to give adequate compensation to truly outstanding inventors that they employ, these inventors are more inclined to stay in Japan rather than immigrate.

—*R. C. Lutz*

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See also: Nick Holonyak, Jr.; Garrett Augustus Morgan.

NAOMI L. NAKAO

Israeli American gastroenterologist

Nakao's invention of a number of devices provided solutions to shortcomings of available medical devices and greatly changed the face of medical technology in gastrointestinal surgery in particular. Some of her products include an endoscopic/laparoscopic stapler, the Nakao Snare line, and the Nakao EndoRetractor.

Born: January 13, 1948; Jerusalem, Israel
Also known as: Naomi Low Nakao (full name)
Primary field: Medicine and medical technology
Primary inventions: Nakao Snare; Nakao EndoRetractor

EARLY LIFE

Naomi Low Nakao was born January 13, 1948, in Jerusalem, Israel. She immigrated to the United States when she was a teenager. After completing her secondary education, she attended medical school at the State University of New York (SUNY) at Stony Brook and completed residencies at the Beth Israel Medical Center and at the Veteran Affairs Medical Center in New York.

LIFE'S WORK

After becoming a practicing gastroenterologist, Nakao experienced frustration on a number of occasions when available medical devices needed during surgical procedures proved to be inadequate to address certain problems optimally. One such experience occurred in 1989 when she and a colleague were treating a patient for a postoperative leak following gastric bypass surgery. They had to watch the patient's condition deteriorate to the point that surgery was not a viable option. Not content to let the matter drop, they set out to invent a device that would allow a surgeon to close such a leak through an endoscope. Once the device was designed, application for a patent was filed in 1989, and the device was licensed in 2001, the first patent ever issued for a device that would enable surgeons to pass it through a flexible endoscope and staple tissue at the site of a leak.

A passionate inventor, Nakao would continue for the next twenty years to find ways to provide the kinds of devices needed to address specific needs. Early on, she discovered that the life of an inventor is not without its problems. Again, she sought a way to minimize the complicated process of obtaining patents on an invention. This resulted in her cofounding Granit Medical Innovations (GMI) with Moshe Granit in 1989. Granit recognized the value of Nakao's work and provided the financial backing for the company. Free of the encumbrances of bureaucracy, GMI was able to bring new products to the market for a reasonable cost and in a timely manner.

In 1991, the Nakao Snare solved a problem known as "lost polyp syndrome." When colon polyps, precursors to colon cancer, are resected with a cautery snare, they often roll down into the colon, necessitating search and retrieval. This is necessary because treatment for a benign polyp is decidedly different from that of a malignant one. The search to recover the polyp so that it can be examined for malignancy is sometimes as time-consuming as is the entire surgical procedure. In the cases of the polyp not being found, proper management of the patient is uncertain. After the Nakao Snare is used to resect the polyp, a second snare with a net is used for retrieving the specimen so that it may be sent to the pathologist in good condition.

Three years later, in 1994, Nakao, with Dr. John V. Mizzi, devised a way to control the flow rate in an intravenous line (IV), thus saving time on the part of nursing personnel and maintaining an even drip rate in a patient's intravenous infusion.

The invention of the Nakao QuickTrap, licensed for use in 2005, was Nakao's solution to the problem of oxygen deficiency experienced by patients during bronchoscopy. Nakao knew of an incident in which a patient's oxygen saturation was dropping while personnel lost almost a minute in the process of using suction-trap tubing that was standard at that time. A comment by the endoscopist that "someone ought to invent a quick trap" led Nakao to do just that.

An endoscope sheath, known as the Nakao Zip-Sheath, was invented to meet the need to cut down on infection transmission during a flexible endoscopy. Before this sheath was available, the process of ensuring that the elaborate, narrow channels in the endoscope were adequately sterilized between procedures was never a completely sure thing; even when strict protocol was followed, microorganisms could remain in the channels of the endoscope. Furthermore, the cleaning materials employed were toxic and harsh, posing a danger to the nursing staff using them.

Another frustration that Nakao faced was that, unlike the case of general surgeons who had retractors at their disposal to enhance visualization of a surgical field during surgery, the gastroenterologist had to rely on air insufflation to visualize lesions inside the colon, and this provided only fleeting visualization that was often insufficient. Added to the frustration was the fact that the blowing of air into the colon risked colon perforation caused by the abdominal distention associated with the air. Determined to meet the challenge, Nakao invented the Nakao EndoRetractor, a device that is introduced into the intestinal lumen before being inflated, thereby opening the area sufficiently to see and treat a lesion. When the procedure is completed, the retractor is deflated and removed.

Some patents have also been issued for some ejection biopsy forceps, marketed under the trademark Nakao Ejector. Nakao saw the need for this device after a veteran endoscopy nurse was injured by a needle stick in the process of trying to free biopsy tissue from the forceps from a patient who was both HIV- and hepatitis B antigen-positive. The nurse felt that she had done something "stupid," but Nakao was insightful enough to see that the design of the biopsy forceps was the culprit and that this risk was present every time a biopsy was performed. Thus, the idea for the Nakao Ejector forceps was born.

In addition to the numerous inventions that provide devices that address weaknesses of existing surgical instruments, Nakao also designed a software program that could aid the endoscopist in detecting premalignant colonic polyps. This automated endoscopy involves the processing of video endoscopic images during a colonoscopy so as to enhance images and facilitate detection and diagnosis of polyps. When the program is used as an automatic system, the computer alerts the endoscopist when a polyp is detected so that the doctor can return to the site for more thorough examination.

While she has a passion for inventing, Nakao has an impressive record in the medical profession. She is associate professor of medicine at Beth Israel Medical Center and the Albert Einstein College of Medicine. A board-certified gastroenterologist, Nakao is an active member in the American Society for Gastrointestinal Endoscopy (ASGE) and the American College of Gastroenterology (ACG). She has served on the ASGE Technology Committee and the Invention Innovation Special Interest Group (II-SIG), a role that, as chair, has made it possible for her to collaborate with medical innovators worldwide. She is actively involved in cutting-edge research and development of medical technology. Having served on the ACG Women's Committee for six years, she has given evidence of her interest in advancing women's interests in medicine.

The Naomi Nakao Gender-Based Research Award is given annually for the best published research paper in the area of gender-related diseases and their treatment. She is a fellow of the ACG and has written or cowritten fourteen articles based on research; she claims fifty-four U.S. patents and patent-pending applications.

THE NAKAO SNARE LINE

The Nakao Snare line may be the best known of Naomi L. Nakao's inventions. Her invention was a direct response to a problem plaguing gastrointestinal surgeons for some time: the problem of losing polyps and risking misdiagnosis, faulty treatment plans, and unnecessary surgery. Since treatment for a malignant polyp differs from that of a benign one, it is essential that the polyp be retrieved in good condition so that an accurate diagnosis can be made.

The Nakao Snare line, which contains three types of snares, was first distributed in 2006. All of the snares function to prevent a severed colon polyp from getting away before it can be collected for pathological testing. The Nakao Snare 1 has a double lumen: one houses a regular cautery snare, the other a retrieval basket. The cautery snare is used to cut away the polyp, after which a second snare with a net is used to hold the specimen. The net is designed in such a way as to slide up and down the snare, cradling the specimen gently so that it can be delivered to the pathology laboratory in perfect condition. The Nakao Cautery Retrieval Snare is designed to both resect and retrieve the polyp in a single maneuver. The net is attached to a larger, outer wire loop, while the smaller, inner wire loop does the cutting. As with the Nakao Snare 1, the polyp is removed without any danger of being lost or damaged. The Nakao Green Net is designed for use in cases in which very large polyps are involved and must be resected in several pieces. As segments of the polyp are removed with a cutting snare, they are caught in the retrieval net, enabling the surgeon to harvest the polyp safely and efficiently.

Nakao is a passionate inventor and a skillful entrepreneur whose goal is to find practical ways of solving medical problems in ways that are efficient and to manufacture her products relatively inexpensively. The Nakao Snare line offers snares that improve vastly on the capabilities of existing ones. Affordability enables physicians to enjoy the benefits of greatly improved methods of removing polyps for pathological testing and enables patients to have confidence that, when they go to surgery, the biopsy samples will be in perfect condition so that accurate laboratory results can ensure that patients will receive appropriate treatment.

IMPACT

A self-declared "novelty" in the medical industry, Nakao does not stop with inventing devices per se but carries the process on to actually producing them, after getting them licensed, through a company that she cofounded precisely for that purpose. Her insistence on not being content with an idea until it has come to fruition as a product that addresses shortcomings in medical instruments used before her product became available has resulted in a number of important innovations in medicine, especially in the area of interventional gastrointestinal endoscopy.

When Nakao and her colleague Peter Wilk watched a patient's condition decline until surgery was no longer an option, she saw the urgent need for some device that would enable her to close a postoperative leak after gastrointestinal surgery. This idea gave birth to Nakao's endoscopic/laparoscopic stapler, which could be inserted through a channel of an endoscope and used to ligate a blood vessel or to close an opening. While there have been several endoscopic staplers invented since then, Nakao's was the pioneering device that paved the way for others. It is impossible to know how many patients will ultimately benefit from this practical invention.

Finding a way to improve the means of administering IVs to a patient was mutually beneficial to both the patient and nursing personnel. In hospitals, when doctors order IVs for a patient, the orders stipulate, in terms of cubic centimeters per hour, the rate at which the fluid is to flow into a patient's vein, converted into the number of drops per minute. The nurse must adjust the amount of constriction on the tubing until the prescribed number of drops per minute is attained. This process takes time initially, and continues to require time to check the flow frequently, since it is not unusual for the drip rate to decrease or increase. The device not only saved time and ensured increased accuracy but also was inexpensive to manufacture.

Likewise, the impact of the endoscopic cauterization snare (Nakao Snare), the ejection biopsy forceps (Nakao Ejector), the QuickTrap, the endoscopic sheath (ZipSheath), and the endoscopy software program is significant in a medical milieu. If a polyp is lost (and the rate of loss is 10-15 percent in the best of hands), surgery that could have been prevented becomes necessary to ascertain whether the patient has a malignancy or not. The biopsy forceps greatly minimize the risk involved in needle pricks that could have disastrous results if a nurse or doctor is working with an AIDS patient. The QuickTrap helps to minimize the amount of time that patients undergoing bronchoscopy have their breathing compromised when the endoscope itself blocks the airway while a tissue specimen is being collected. In view of the fact that two large studies have shown that premalignant adenomas in the colon are missed 25-31 percent of the time and colon cancers are missed 6.2 percent of the time, Nakao's endoscopy software program could play an important role in saving lives.

—*Victoria Price*

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See also: Marie Anne Victoire Boivin; Gertrude Belle Elion.

JOHN NAPIER

Scottish mathematician

Napier spent twenty years developing his tables of logarithms. Calculations necessary in navigation and astronomy were greatly simplified by this work since difficult multiplication and division problems could be reduced to additions and subtractions.

Born: 1550; Merchiston Castle, near Edinburgh, Scotland
Died: April 4, 1617; Merchiston Castle, near Edinburgh, Scotland
Also known as: John Neper; eighth lord of Merchiston
Primary field: Mathematics
Primary inventions: Logarithms; Napier's bones

EARLY LIFE

John Napier was born in Merchiston Castle in Edinburgh, Scotland, in 1550. His father was Archibald Napier, whose family had owned the estate at Merchiston since the early part of the fifteenth century. His mother, the former Janet Bothwell, was the daughter of Sir Francis Bothwell, the provost of Edinburgh. Sources agree that Archibald was only fifteen years old at the time of his marriage to Janet in 1549. There is no uniformity regarding Janet's age, however. It is listed anywhere from fourteen to nineteen at the time of the marriage. In any case, John was born the following year. The family used a variety of spellings for their surname, including Nepair, Neper, and Napare. The modern spelling was not standard until well after John Napier's death.

Napier was educated at home until he enrolled at the University of St. Andrews in 1563. Not long after that, his mother died. No records exist to show that Napier completed a degree at St. Andrews. It is likely that he left the university to study on the Continent, but he later wrote that his time at St. Andrews inspired his first love of theology. It was then that he began to study the book of Revelation. In 1593, he published a tract on that book, which he regarded as the most important intellectual contribution of his life. In his *Plaine Discovery of the Whole Revelation of St. John*, he revealed his pro-Reformist and anti-Catholic sympathies by arguing that the pope is the antichrist.

Napier married Elizabeth Stirling in 1573; together they had a son and a daughter before Elizabeth died at the age of twenty-seven in 1579. In 1582, Napier married again. Agnes Chisholm was to bear him five sons and five daughters.

LIFE'S WORK

Napier's opinion that his *Plaine Discovery* was his greatest accomplishment notwithstanding, history has crowned his invention of logarithms as his most notable contribution. As early as 1594, he had begun to work on what he termed "logarithms." He coined this new term from two Greek words: *logos*, meaning "reckon," and *arithmos*, meaning "number." He saw logarithms as "reckoning numbers," that is, as numbers that could be used to facilitate the process of reckoning, or calculating, especially with regard to multiplication, division, and extraction of roots. Although Napier may not have been the first person to entertain the concept of the logarithm, he was the first to put that idea into practice and to develop it so thoroughly.

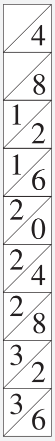
Napier's conception of the logarithm was kinematic—that is, he used the relationship between two different motions to establish the logarithm. He supposed that he had a line segment of some particular length, AB. Napier chose the length of AB to be 10^7 units. A second segment, actually a ray, begins at point C and extends through D to infinity. At time $t = 0$, a point S begins traveling along CD at a fixed velocity v_0. At the same time $t = 0$, a point R begins traveling along AB beginning at A. Although its initial velocity, like that of S, is v_0, its velocity is always proportional to the distance from R to B. Therefore, its velocity is ever decreasing as R approaches B and will be 0 when R reaches B. At some time t, R is x units away from B and S is y units away from C. Napier defined the logarithm of x to be y. This is sometimes written as "Nap. log $x = y$" for "Napierian logarithm."

Once Napier had his concept in place, he began constructing tables of values. He needed an extensive set of tables in order to be able to represent any number, if not exactly, then at least with a very good approximation. He chose to begin with the number ten million. He then subtracted one ten-millionth (10^{-7}) of 10 million, or one. He repeated this process one hundred times, each time subtracting 10^{-7} of the previous result. After one hundred steps, his last table value was 9,999,900.0004950. By successively reducing the amount to be subtracted, Napier produced the effect of the reduced velocity on segment AB that was described previously. In this table, Napier provides one hundred numbers in close proximity to one another. Multiplying or dividing two of them corresponds to adding or subtracting their logarithm values.

Napier's Bones

Although John Napier is remembered most for his work on logarithms, this is not the only invention that contributed to his fame. In 1617, after he had published his tables of logarithms, he published *Rabdologiae* (study of divining rods). In some circles, Napier is better known for the rods, or "bones," than for his logarithms.

Napier described a set of ivory rods that could be used as a calculating device. These are often referred to as "Napier's bones" since the ivory material gave the rods the appearance of bones. On each rod was written the result of multiplying any of the single digits by zero through nine. For example, the rod for the number 4 might look like this:



A "bone" was really a four-sided rod. It was three-dimensional, with a square cross-section. Each of its four sides contained the digits for one or the other of the rods.

The bones may then be used, for example, in multiplication. As an illustration, if one wanted to multiply 6,754 by 28, one would take the bones for the numbers 6, 7, 5, and 4 and lay them next to each other in order. To multiply this number by 8, the person goes down to the row that represents the multiples of the digits by 8 and reads across, diagonally, from right to left. If necessary, any sum is carried to the next diagonal column, as is similarly done in the usual multiplication algorithm. To multiply by twenty, the same is done in the row containing the multiples of the digits by 2, but a zero is appended at the end since one is actually multiplying by 2×10, not just by 2. Adding the two results will produce the final product. The example may be extended to two factors with any number of digits, as long as there are enough bones to represent one of them.

In this way, Napier provided a way to transform a multiplication problem into an addition problem, for no multiplications are performed in the procedure just described, but only additions. His "bones" allowed for a practical implementation of the concept of lattice multiplication, which was introduced in Europe by Leonardo of Pisa (also known as Fibonacci) in the thirteenth century. Napier's device proved to be quite popular throughout Europe. Because of the great interest, the *Rabdologiae* was translated from the Latin into Dutch and Italian.

It should also be noted that in representing the numbers in his table in this way, Napier also revealed a second invention: the decimal point. As with logarithms, it is possible that others may have had a similar concept, but Napier was the first to describe it explicitly and to use it so widely.

After rounding the last number in his table to 9,999,900, Napier began a second table with this rounded number. This table contained fifty values, and the subtractions were by 10^{-5} of the previous result instead of 10^{-7}. Unfortunately, this second table included a mistaken value. The astronomer Johannes Kepler found the error and corrected it when the tables were republished.

The third and final table used a subtraction factor of 0.005 of the previous result. It included sixty-nine columns and almost fifteen hundred numbers. Once this table was in place, Napier proceeded to assign a logarithm to each of the values, using the concept described above. He also developed interpolation procedures for assigning logarithms to numbers not found in the tables. By constructing the second and third tables with larger subtraction factors, Napier was able to produce bigger ranges of values for which to assign logarithms.

Work on this project consumed the better part of twenty years of Napier's life, from 1594 until he published the *Mirifici logarithmorum canonis descriptio* (1614; description of the wonderful canon of logarithms). The tables described above took 90 of the book's 147 pages.

Napier's logarithms are not precisely the same as the logarithms in use today. For example, though it is now understood that $\log_b 1 = 0$ for any base *b*, this was not the case for Napier. In fact, his logarithms, strictly speaking, are not to any base. In 1615, the English mathematician Henry Briggs began a correspondence with Napier about the logarithms. Briggs also traveled to Edinburgh to meet with Napier to propose that the logarithms be recalculated to what is now called the "common log": $\log_{10} x$. Napier saw the advantages and agreed, but he revealed that his poor state of health would prevent him from producing the new calculations. Briggs himself completed the project with the publication of *Arithmetica logarithmica* in 1624.

In fact, Napier did not live long past the publication of his tables of logarithms. He died in April of 1617. The nature of his final illness is not certain; however, his lifespan of sixty-seven years was certainly longer than that of most of his contemporaries.

IMPACT

Unlike so many advances in science and technology, Napier's invention of logarithms had no known precursor. It seemed to come from nowhere. While it is possible that some others had entertained related ideas, Napier was the one who fully developed logarithms and made them accessible to others. As soon as the tables were published, they were recognized for their utility. For example, navigators often were forced to do many calculations in order to chart their courses, and too often made errors. The East India Company immediately engaged a mathematician to translate the *Mirifici logarithmorum canonis descriptio* into English so that the company could begin to use the logarithms. Likewise, the calculations that astronomers had to perform were greatly simplified through the use of logarithms. In fact, eighteenth century mathematician Pierre-Simon Laplace, who also studied astronomy, once remarked that Napier's logarithms, "by shortening the labors, doubled the life of the astronomer."

Almost immediately after the publication of the *Descriptio*, scholars began working to implement Napier's ideas. For example, by 1630 English mathematician William Oughtred had developed the slide rule. Although the form of the instrument changed over the years, the concept remained the same: The instrument has both a linear scale and a logarithmic one. By sliding one scale against the other, the user may use the principles of logarithms to determine the answer to a multiplication or division problem.

A final indicator of the impact of Napier's work is that slide rules were not overtaken by calculators as the most common instrument used in education and industry until about the 1970's. Schoolchildren continued to be taught how to use tables of logarithms in their calculations until the 1980's, almost four hundred years after Napier first published his work. Handheld calculators have finally made logarithm tables obsolete.

—*Michael J. Caulfield*

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Napier, Mark. *Memoirs of John Napier of Merchiston, His Lineage, Life, and Times, with a History of the Invention of Logarithms*. Edinburgh: William Blackwood, 1834. Republished in 1904, this 500-plus-page book was written by a direct descendant of John Napier. It tells the life of Napier in great detail and includes the history of the family name and coat of arms. The description of Napier's life and exploits, however, is probably more favorable than an objective reviewer would provide.

See also: Gottfried Wilhelm Leibniz; Sir Isaac Newton.

JAMES NASMYTH

Scottish engineer

Nasmyth's steam hammer was a significant metallurgical tool of the budding Industrial Revolution. Developed to forge a shaft for a ship, the steam hammer allowed mechanization of tasks ranging from forging steel to hammering a nail. Nasmyth also invented a planing machine and a punching machine.

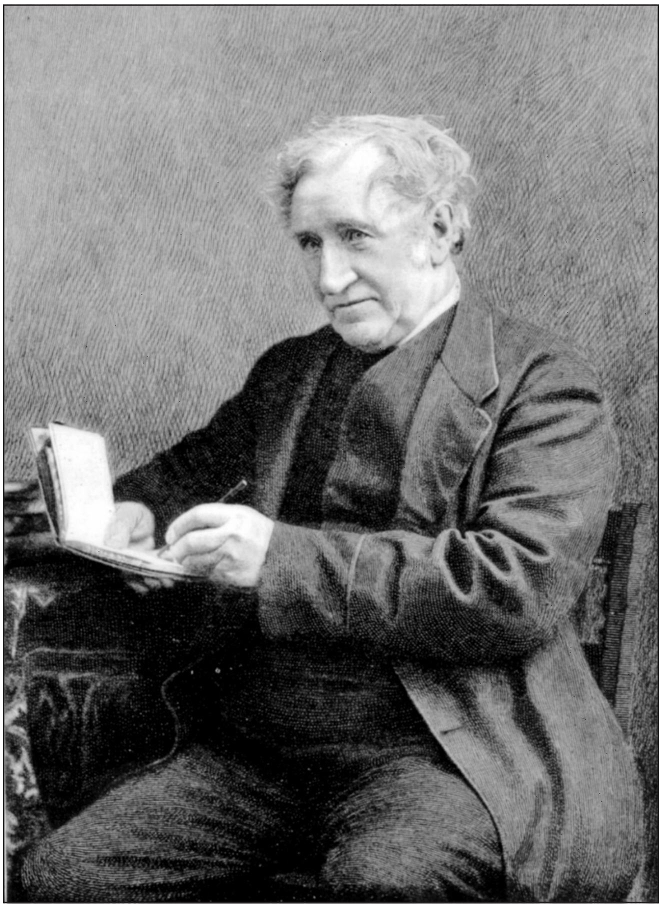
Born: August 19, 1808; Edinburgh, Scotland
Died: May 7, 1890; London, England
Also known as: James Hall Nasmyth (full name)
Primary fields: Civil engineering; naval engineering
Primary invention: Steam hammer

EARLY LIFE

James Nasmyth (NAS-mihth) was born in Edinburgh, Scotland, in 1808. His father, Alexander Nasmyth, was an artist by profession, whose hobbies included civil engineering and mechanics. James's oldest sister, Jane, taught him his alphabet and basic reading. He then attended a one-room school to learn English, but his father withdrew him because of the tutor's excessive use of corporal punishment. Young Nasmyth then entered Edinburgh High School in October, 1817, where he studied Latin, much to his chagrin. In high school, Nasmyth befriended Jemmy Patterson, whose father owned an iron foundry where Nasmyth spent much of his free time learning various aspects of metal casting and forging from the foundry's workers. He made small brass cannons and little handguns out of cellar keys for his fellow schoolmates.

Nasmyth left high school in 1820 and began attending private classes on mathematics and geometry, which he found much more to his liking. He continued to learn mechanics from his father, who also taught Nasmyth mechanical drawing. Nasmyth then attended the Edinburgh School of Arts from 1821 to 1826, studying mathematics, chemistry, and mechanical philosophy. He made working models of steam engines in his father's workshop for the teachers to use in their classes. He went on to make and sell steam engines to commercial entities.

In 1837, Nasmyth became intrigued by steam carriages that ran on roads. He constructed a working model that he exhibited to the Royal Scottish Society of Arts. Impressed by his model, the society provided him with funds to build one that could transport four to six people. He completed the carriage in four months and made several runs with it, carrying up to eight passengers per run. The society, however, did not see a commercial application for Nasmyth's carriage, so Nasmyth parted out and sold its components.



James Nasmyth. (Library of Congress)

LIFE'S WORK

Nasmyth was determined to secure employment at Henry Maudslay's foundry in London, but Maudslay, disappointed with the performance of previous apprentices, had decided not to accept any more. Nasmyth assembled a portfolio of his drawings, built a working model of a pressure engine, and in 1829 set out for London with his father to plead his case to Maudslay. Maudslay was so impressed by the young man that he took him on, not as an apprentice but as his assistant. On May 30, 1829, Nasmyth began working for Maudslay. His first two designs were a hexagonal nut-cutting machine for Maudslay and an indoor cooking apparatus for himself so he could make his own dinners in his small apartment. Nasmyth worked on such diverse projects as a two-hundred-horsepower steam engine and a telescope for his mentor. Sadly, Maudslay died on February 14, 1831, and Nasmyth continued on with his partner Joshua Field until August when, at age twenty-three, he decided it was time to go into business for himself.

Nasmyth went back to Edinburgh for three years, and he eventually set up his own factory in Manchester, England. He quickly received orders and was able to hire several workmen and to purchase additional machinery. When his business grew, he opened another foundry in Bridgewater and entered into a partnership with Holbrook Gaskell. In 1838, he invented the safety foundry ladle, which allowed workers to pour molten metal from behind the ladle rather than next to it, protecting workers from the danger of being set ablaze from spilled hot metal. He chose not to patent his invention but offered it to the public to help save lives of foundry workers.

On May 2, 1838, Nasmyth visited Sheffield; on his way home, he noticed a foundry in Barnsley. He discovered that it belonged to a Mr. Hartop, whom he had met some years earlier, so he stopped to visit. There he met Hartop's twenty-one-year-old daughter Anne and quickly fell in love with her. They were married on June 16, 1840, and remained happily married until his death fifty years later. They had no children.

Nasmyth was awarded a contract to work on the locomotives for the Great Western Railway Company. When the company embarked on construction of its biggest steamship yet, the SS *Great Britain*, it was unable to find anyone with a forge hammer large enough to make the thirty-inch-diameter paddle shaft for the ship. Nasmyth went to work on the problem and sketched out the design of his steam hammer in less than a half hour. The Great Western Railway Company approved his design, but before it could be built the company abandoned the paddle-wheel design in favor of a screw.

The steam hammer remained just a drawing in his "Scheme Book" until one day, while Nasmyth was away, his partner showed Nasmyth's drawing to the proprietor of the ironworks in Le Creusot, France, but did not mention the encounter to Nasmyth. In April, 1842, Nasmyth was astonished to find that the foundry in Le Creusot had built a steam hammer based on his design and that his invention had been used to forge a ship's crank. Nasmyth had not patented his design because of the cost but now rushed to do so, using funds he borrowed from his brother-in-law. Two months later, in June, 1842, he received his patent. He went on to patent the hammer in the

THE STEAM HAMMER

Before James Nasmyth invented the steam hammer, the trip hammer was used. These hammers, made of wood or metal, are basically large horizontal shafts attached to a pivot point with a heavy hammer end, raised at the base of the shaft by a cam and then gravity-dropped. The first written description of these hammers came from China in 40 B.C.E., where the hammer was used instead of a mortar and pestle to pound grain. By the first century C.E., China was using a water-powered hammer for pounding metal. Ancient Greece also used water-powered trip hammers for agriculture, and Rome used them for both agriculture and metallurgy. They were used in the Middle Ages in Europe, and Leonardo da Vinci made many sketches of them in use in forges. The problem with the trip hammers is that they could not be raised very high, and they delivered a limited and uniform power blow. Thus, they were suitable only for relatively small projects, such as shaping brass pots, pans, and cutlery or making bar iron out of pig iron.

Nasmyth's steam hammer worked vertically, which allowed it to deliver much greater forces and to work larger and thicker pieces. His hammer was raised vertically by a steam-powered cylinder and then allowed to free-fall. He later modified his design to inject steam into the top side of the cylinder after the hammer had been raised, thus driving the hammer down with steam power and increasing the force of the dropping hammer. By using the steam-powered cylinder to raise and drop the hammer at varying heights, the steam hammer could deliver a hard blow or a gentle pat; Nasmyth enjoyed demonstrating his machine by first dropping the hammer at full force, shaking the building it was in, and then dropping it so gently that it broke an egg in a wine glass without even chipping the glass. Nasmyth immediately saw that his vertical hammer could easily be modified to create a pile driver, which Nasmyth patented the year after he patented the steam hammer.

To give an idea of how large and powerful the steam hammer could be, in 1877 the foundry in Le Creusot, France, built a hammer with legs that were more than ten meters long and a cylinder that was six meters high with a 750-ton anvil. It could deliver a 3.3-million foot-pound force. The hammer is no longer operational but is still on display in Le Creusot.

United States as well. He manufactured his hammer in England, and it was used to forge anchors and allowed the die and stamp system to finally be used on a large scale. By the time he retired in 1856, Nasmyth, Gaskell and Company had sold almost five hundred steam hammers, which accounted for 40 percent of the company's profits.

Nasmyth anticipated that his steam hammer could also be used as a pile driver and patented this design in 1843. The Royal Navy commissioned Nasmyth to erect his drivers in Devonport to build a large dock for the navy's ships. On July 3, 1845, he had a good-natured competition with the workers at the docks, pitting his pile driver against a crew using the old, hand-operated one. Nasmyth's device drove a seventy-foot-long, eighteen-inch square pile in 4.5 minutes compared to the old machine, which took twelve hours. His pile driver became an international success.

Nasmyth retired in 1856 to have more time to enjoy astronomy, his longtime hobby. He built a telescope to observe the Moon. He coauthored a book about the Moon that included photographs of models of the Moon that he constructed based on his observations.

IMPACT

Nasmyth dedicated himself to learning all aspects of engineering, and his tireless dedication to his craft allowed him to invent simple but effective machines. He believed that the ability to perform mechanical drawing was critical to the engineer, because without it the worker is only a hand, but the ability to draw shows he also has a head. He learned from Maudslay's maxims that if one has a clear idea of what one wants to achieve, one will bring it to fruition, that one should avoid the complex and keep designs as simple as possible, and that one should eliminate every ounce of material one can do without. Nasmyth was never without his "Scheme Book," in which he sketched his ideas.

While Nasmyth is known mostly for his development of the steam hammer, which revolutionized large-scale forging, and his pile driver, which expedited bridge, dam, and dock construction, he also built more than one hundred steam engines and other tools that contributed to the Industrial Revolution by accelerating production. He also furthered development of tools and machines by using standardized sizes of machine tools that could be interchangeable and compatible with other machines and tools. He patented some of his creations, but others he left to the public to augment work safety or increase mechanization.

—*Polly D. Steenhagen*

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See also: Sir Henry Bessemer; Charles Martin Hall; William Murdock.

HENRI NESTLÉ

German Swiss pharmacist

Nestlé's most notable invention was devised in response to the infant mortality rate: an infant formula for bottle-fed babies. Nestlé also contributed to the production of absinthe, carbonated mineral water, lemonade, liqueurs, nut oils, rapeseeds, rum, and vinegar. After his death, his company went on to produce milk chocolate, instant coffees, and several other processed foods.

Born: August 10, 1814; Frankfurt am Main (now in Germany)
Died: July 7, 1890; Glion, Vaud, Switzerland
Also known as: Heinrich Nestle (birth name)
Primary field: Food processing
Primary invention: Infant formula

EARLY LIFE

The eleventh of fourteen children, Heinrich Nestle (HIN-rihk NEHS-uhl) was born in Frankfurt am Main (now in Germany) on August 10, 1814. His mother was Anna-Maria Catharina Ehemann; his father was Johann Ulrich Matthias Nestle, a glazier in Töngesgasse who had by tradition inherited the business from Heinrich's paternal grandfather.

In his teens, Nestle worked for pharmacist J. E. Stein, completing his apprenticeship in 1834, a few months before he turned twenty. By 1839, at the age of twenty-five, he was officially a pharmacist's assistant, authorized to perform such duties as those of a merchant selling medicines, a pharmacist's assistant making and filling prescriptions, and a small-scale inventor conducting chemical experiments. With such experience, Nestle moved to Vevey, Switzerland, changing his name to Henri Nestlé (then pronounced ahn-REE nehss-LAY; the latter in America now pronounced NEHS-lee)—reportedly a more French-sounding name that would allow him to better fit in with the society.

The inventor-merchant began the next phase of his career by investing, in 1843, in rapeseed production (for manufacture of a variety of foodstuffs such as canola oil) and adding to his repertoire by getting into the production, manufacture, and sales of nut oils, drinking alcohols, vinegar, carbonated mineral water, and lemonade. By 1857, Nestlé had also become involved in gas lighting (as opposed to nut oils used for lighting) and in fertilizers as a resource.

LIFE'S WORK

In May of 1860, Nestlé married Anna Clementine Therese Ehemant and soon thereafter adopted a daughter, Emma Seiler, who had been born in 1845. Sometime during these years, Nestlé had begun experimenting with another foodstuff—children's groats. Nestlé created Farine Lactée Henri Nestlé (Henri Nestlé's milk flour), an instant infant formula of powdered cow's milk, malt, sugar, and chemically altered wheat flour (with the acid and starch, difficult for infants to digest, removed), which required only the addition of water.

That year, the first Nestlé product was born, manufactured in the inventor's hometown in the first factories in Vevey. The baby formula was so popular that within four months after its launch, it was sold in five European countries. By 1868, to meet the demands for orders, Nestlé was compelled to open a second office in London. By 1873, the company had expanded even further, exporting the product as far away as Australia, South America, and North America and selling 500,000 boxes worldwide. The following year, Nestlé sold his company to business associates for one million francs and retired. He lived with his family alternately in Montreux and Glion, the latter the location of his home that would be dubbed Villa Nestlé. From his retirement in 1875 until his death in 1890, Nestlé contributed to the financial well-being of Montreux and Glion, making donations to the community and helping individuals with small loans.

The company Nestlé had founded also went on to diversify: In 1905, the company bought out Anglo-Swiss Condensed Milk (where today a second head office sits in Cham, near Zurich); in 1929, Nestlé bought out chocolatiers Peter, Cailler, and Kohler. In 1938, Nestlé introduced another instant marvel—the world's first instant coffee, Nescafé. These successes were followed by the company's 1947 takeover of Maggi, a manufacturer of processed food; the 1950 buyout of Cross and Blackwell; and the 1963 purchase of Findus, a frozen-food conglomerate. Headquartered on the coast of Vevey, Nestlé was Switzerland's largest company by the mid-1960's.

Nestlé was not without its problems. For all the quality innovation that accompanies the Nestlé name, so is there an ironically controversial aspect of its reputation that the Nestlé Company today still works to live down—a controversy beginning with that for which Nestlé was first renowned: the Nestlé infant formula. In the mid-

1970's, the Nestlé Company allegedly ran aggressive marketing campaigns that included hiring graduate nurses in the Philippines to serve as health educators who visit new mothers in their homes and promote the use of Nestlé formula; running Baby World Clubs for the health education of (and product promotion targeting of) pregnant Singapore women; extensive ad campaigns touting bottle-feeding as the more "modern" method to breastfeeding; dispensing formula samples to new mothers; and running extensive advertising campaigns for such infant milk products as "follow-on" (post-breast-feeding) milk. In countries such as the United Kingdom, Nestlé infant formula product was banned for allegedly causing rickets and blindness. In developing countries, great numbers of new mothers were reportedly using the infant formula improperly, adding contaminated water to commercial infant formula, using unsterilized feeding implements, and/or, unable to afford the formula in its purest form, excessively diluting the formula—resulting in diarrhea, malnourishment, and even death in many instances.

Critics maintained that formula companies such as Nestlé were informed of the risks, were denying any culpability, and were increasing the risks by continuing their profit-driven, aggressive marketing to supply products (with labels written only in English and therefore eluding the understanding of users in developing countries) to those women dependent on the products and unable to protect themselves or their babies. U.S. government brochures warning of the dangers of improperly used breast milk substitutes and unsuccessful attempts to convince Nestlé and other companies to alter their practices led several groups—such as the International Nestlé Boycott Committee, the International Baby Food Action Network, and the Baby Milk Action—to call for a boycott of Nestlé products. These efforts resulted in the 1981 adoption by the World Health Assembly of an infant formula marketing code, one imposing tighter restrictions on composition, labeling, and marketing of infant formula products.

Nestlé has likewise changed its policies and practices, stopping all general advertising, halting the promotion of formula by the so-called milk nurses, stopping the dispensing of free samples, and creating infant formula labels and instructions that comply with the World Health Organization (WHO) code requirements. The company that had begun as a one-man vision to produce infant formula had by 1974 purchased the L'Oréal cosmetics company and by 1991 taken over Rowntree's, the British confectioners company, moving into the twenty-first century as a multinational corporation boasting more than two hundred factories around the globe and employing almost a quarter of a million people. Although reportedly still on the defensive with regard to the boycott, today Nestlé carefully instructs company personnel involved in the interpretation and compliant implementation of the WHO code, makes use of an Audit Commission staffed by neutral, non-Nestlé individuals who monitor infant formula practices, and continues to assert the company's ethos begun by Henri Nestlé: that of enduring quality.

THE NESTLÉ INFANT FORMULA

Though his name is associated with delicious chocolate, Henri Nestlé is first and foremost known for his invention of an infant formula that saved lives. In the nineteenth century, mothers who did not, or could not, breast-feed typically opted for either a wet nurse or for dry nursing—making their own infant foods. In the mid-1840's, however, there was a frightening increase in medical issues and mortality rates for infants. Scientists at the time attributed the problems to the dry-nursing habits of mothers who did not breast-feed. Around the same time, Nestlé began working on his own infant formula—his interest in the product attributed to his concerns with the high infant mortality rate in Switzerland and the mortality rate in his own family. (Half of Nestlé's thirteen siblings died before reaching adulthood.) Experimenting with various recipe combinations, he started his formula by mixing cow's milk, sugar, and wheat flour. He then enlisted the aid of colleague and nutritional scientist Jean Schnetzler, who helped him remove the hard-to-digest acids and starches. In 1867, Nestlé fed this "wholesome Swiss milk and cereal component baked by a special process of [his] invention" to a premature baby, saving the infant's life. His formula, Farine Lactée Henri Nestlé (Henri Nestlé's milk flour), was on its way to becoming a household name; within a few short years, it was modified (having the addition of malt) and was selling throughout Europe and the United States.

Nestlé's formula has since changed the lives of adults and infants the world over. Its value has become recognized as "ideal for delicate infants" and lauded for its nutritional beneficence for infants unable to take their mother's breast milk. It has also aided mothers who cannot breast-feed and relieved mothers of the duty of breast-feeding so they can work. Nestlé's formula has been exported to developed and developing countries around the globe as a life-enhancing, even life-saving, product.

IMPACT

Nestlé invented a baby formula that saved lives and contributed to the lowering of the infant mortality rate in the mid-1800's. Nestlé also inadvertently contributed to the perfecting of the condensed milk-making process and to the industrializing of Daniel Peter's company's milk chocolate. For instance, in 1905, after the death of both Nestlé and Peter, the founders' companies worked together to produce the very sweet Nestlé's milk chocolate, which appealed to the French palette as well as to the tastes of people the world over.

Further, Henri Nestlé was one of the first to make an immediate transition from a home market to a global marketplace. As a pioneer in the food and foodstuff industry, Nestlé instigated one of the earliest global-scale product-cycle patterns—seeing the company into first the local market (Switzerland), then to exporting, then to international production. According to former Nestlé chief executive officer (CEO) Peter Brabeck-Letmathe, it was typical of Swiss food companies' objectives to tend toward the foreign markets in order to cope with the limited size of the domestic market. Other important factors contributing to this trend were the increasingly high import duties, the imperative of remedying rising average costs by increasing plant size, and the ensuring of a steady supply of essential products at the (local) retail level by having a local presence (such as was in the case with the Nestlé Company).

It was because of Henri Nestlé's insightfulness, or visionary aptitude, that the Nestlé Company would come to make such an impressive impact at the global level. He took his company international immediately; established an independent brand by creating his own manufacturer's brand; and created a unique identity, positively exploiting the Nestlé name by using the German origin of the name, "little nest," to secure a memorable, marketable image to inspire trust and confidence in consumers who were reassured by his "seal of quality." This world-renown characteristic of the Nestlé Company has also helped to maintain Switzerland's reputation as a country with a long history of innovation and subsequent high-quality production.

—*Roxanne McDonald*

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See also: George Washington Carver; John Harvey Kellogg.

THOMAS NEWCOMEN

English mechanical engineer

Newcomen developed the first successful atmospheric steam engine to do practical work and thereby laid the foundation for the industrial age.

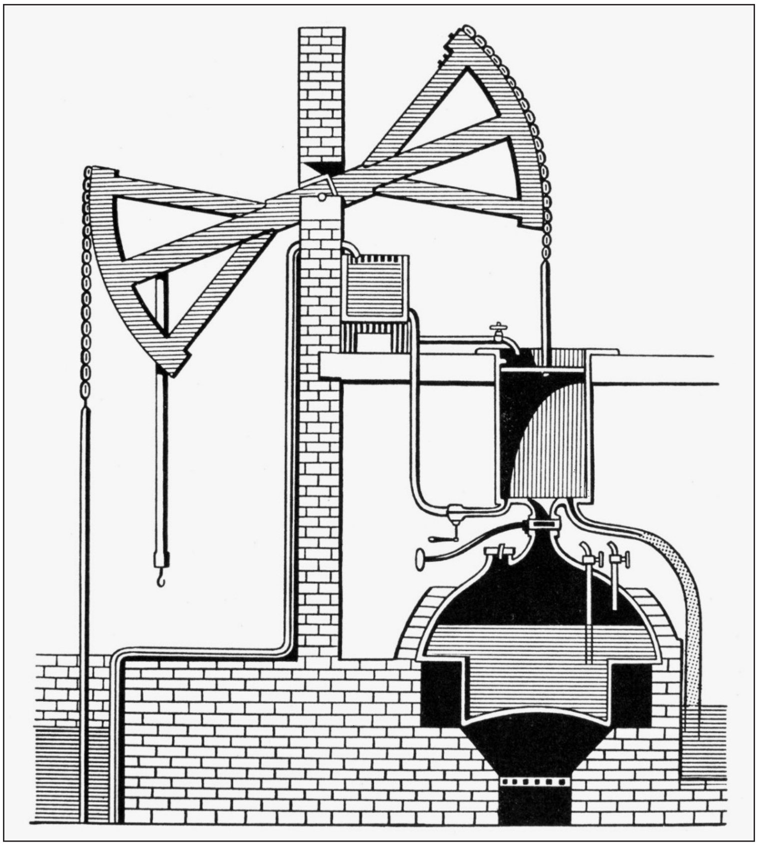
Born: January or February, 1663; Dartmouth, Devon, England
Died: August 5, 1729; London, England
Primary field: Mechanical engineering
Primary invention: Atmospheric steam engine

EARLY LIFE

Thomas Newcomen (new-KUH-muhn) was the second son of Elias and Alice Trenhale Newcomen of Devon, England, born shortly before February 24, 1663, the date of his christening at St. Savior's Church in Devon. He seems to have been apprenticed to an ironmonger in Exeter, for by 1685 he was established in this trade in Devonshire. A popular story has it that he first conceived of the idea of steam doing work as a youth by watching a boiling tea kettle and noticing that the lid would rise and fall once the water was boiling.

He must have enjoyed some success at his trade, because around 1689 he purchased twenty-five tons of iron from a nearby ironworks that he made into various objects and sold in the region. In 1704, he repaired the town clock and so came to acquire the reputation of one talented in ironworking. Also, by this time he had taken on a partner, John Cauley, a plumber and glazer. Both were Baptists; indeed, Newcomen was a lay preacher. This is not especially surprising: Most of the early English industrialists were Dissenters of one sort or another.

In 1705, while in his early forties, Newcomen married Hannah Waymouth of Marlborough, also a Baptist. They leased a house on the high street, which functioned as the home in which they raised their two children, Thomas and Elias. There, Newcomen held religious services and carried on his researches into the steam engine along with his trade. The home came to be known as the Newcomen House until it was demolished in 1864.



A schematic of Thomas Newcomen's steam engine from 1712. (The Granger Collection, New York)

LIFE'S WORK

Newcomen's accomplishment was his steam engine. While relatively costly to operate, it enabled water to be pumped out of mines efficiently at depths hitherto impossible. However, his steam engine was greatly improved upon by James Watt and Matthew Boulton and was not the earliest engine, so the question arises, how important were Newcomen and his engine?

Contemporaries, perhaps blinded by ideas of class, suggested that he received crucial help from Robert Hooke, with whom he corresponded, or perhaps stumbled by accident upon the methods he needed to produce his machine. To these contemporaries, a mere ironmonger could not have been capable of solving a problem that learned academics had failed to solve. Others suggested that his success lay in bringing together ideas that had been developed by other men. Still other scholars, most especially his biographers L. T. C. Rolt and J. S. Allen, insist that the work was his alone. Newcomen may well have been familiar with the efforts of his immediate predecessors, but his engine was his own contrivance. His wife suggested that he worked on his engine in secret in their home for about four years. When curious neighbors asked what he was working on, she always replied that she did not know but, as she knew him to be an honest and upright man, was not at all concerned.

There were two precursors whose failed attempts are indeed reflected in Newcomen's successful engine. The first was Denis Papin, a Huguenot who fled to London to escape religious persecution in France. He was fortunate enough to enjoy the support of Hooke and Robert Boyle and soon gained admittance into the Royal Society. There, he demonstrated a kind of engine that used steam to drive up a piston, generating a vacuum that when cooled would drive down the piston by atmospheric pressure. This is the very principle that Newcomen would apply to great effect in his engine. Papin, on the other hand, did not develop his machine into anything more than a novelty.

The second precursor was Thomas Savery, also of Devonshire, who in 1698 patented a device he called the "Miner's Friend." This device was modeled after one of Edward Somerset's designs and was built to supply water for fountains. It employed two containers alternately filled with steam, then sprayed with cold water to cause condensation and the creation of a partial vacuum into which water would rise from a well. Savery received a royal patent for his device in 1699 that extended the patent until 1733. Unfortunately, despite all his efforts, he was never able to overcome the fact that it could not be used at depths greater than seventy feet. It was useless as a device for extracting water from mine shafts.

It cannot be known with certainty when Newcomen began to work on the problem of lifting water from mine shafts by steam power. His work carried him to tin mines, and he would doubtless have been aware of their problem with water in deep shafts. He very likely was acquainted with Savery, who most certainly knew Papin. However, there is some evidence from the period that suggests that Newcomen owed little or nothing to these two men. A Swedish engineer, Mårten Triewald, who was studying English mining techniques and traveling in Devonshire during this period, along with Stephen Switzer, a writer on hydraulics, both maintained that Newcomen's engine was developed independently of its precursors. Whatever may be the truth, once Newcomen had developed his engine, he decided to go in with Savery to use his patent instead of seeking one of his own, a move advantageous to both men, according to Newcomen's biographers.

The first Newcomen engine seems to have been erected by 1712. It worked by placing a boiler directly above a piston chamber, which was attached via a chain to one side of a rocker arm, the other side of which was attached to a pump rod heavier than the piston. Steam from the boiler was allowed to pass into the chamber, which filled the piston chamber opened up by the weight of the pump rod. Once this chamber filled with steam, it was sealed off and cold water was introduced inside, causing

THE ATMOSPHERIC STEAM ENGINE

Thomas Newcomen's steam engine went through many iterations, each addressing problems raised by the one that preceded it. The engine employed a boiler, usually of the "haystack" variety, so called because of its shape. This type was larger than those that preceded it and was appropriate only for low-pressure steam systems such as Newcomen used. Because of the low pressure, it was also less likely to explode than earlier versions.

As it was not technically possible to engineer perfectly round objects at that time, Newcomen guaranteed that he had a vacuum by means of a leather ring seal. It was also necessary to keep water on top of the piston. Atop the piston was a water supply that was injected into the bottom to bring about the condensation. As the engine became more sophisticated, it included a secondary pump also attached to the pump side of the fulcrum that supplied water for this water tank from water pumped out by the pump rod.

Most images of the engines show very little of the pumps that were used—most seem to have been deadweight force pumps. These overcame the limitations of Thomas Savery's engine because the suction stroke was only the length of the upward stroke of the piston.

The greatest problem with Newcomen's engine was its inefficiency. James Watt applied new ideas about latent heat to modify a Newcomen engine he had been given to repair. Realizing that it was the heating and cooling of the engine that caused it to wear out, Watt created a separate condenser that allowed the cylinder temperature to remain constant. Other improvements enabled this engine to be connected to a rotary shaft, thus creating an engine with all the features known today.

the steam to condense, creating a vacuum, and allowing the atmospheric pressure above to force the piston down while pulling up the pump, thereby drawing the water out from the mine. Through an elaborate series of secondary pulleys and valves, the process could be repeated twelve to fifteen times per minute, each cycle drawing out about two gallons of water that was then drained off. The machine could run night and day. It is easy to see why it was so popular.

By 1725, there were at least one hundred of the steam engines in use in England and elsewhere. Even after Watt's improved engine was introduced in 1769, Newcomen's continued to be built. Only after Watt's patent expired in the 1790's (significantly lowering his price) did his machine finally replace the Newcomen engine. Still, some Newcomen steam engines continued to be used (and somewhat modified) until the twentieth century.

Not much is known about Newcomen's later life. Business regarding his engine was taken over by an unincorporated company, "Proprietors of the Invention for Raising Water by Fire." Indeed, Newcomen does not seem to have made a lot of money from his invention and apparently was content to spend much of his time preaching and teaching. He died in London in 1729.

IMPACT

Early in the eighteenth century, Newcomen developed the first atmospheric steam engine that really worked. In so doing, he provided assistance to the mining industries of his era for whom shaft flooding was a serious problem. More important, he demonstrated that steam power could be harnessed to do work. By the end of the century, the Industrial Revolution was taking off in England, and it was largely powered by steam engines of many types rather than the more unpredictable water power. It is fair to say that the industrialization that so transformed the world would have been impossible without Newcomen's work. As it were, he unstopped the dam that was holding back industrial progress and allowed the process to proceed in earnest.

—*Terry R. Morris*

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See also: Robert Fulton; Robert Hooke; Thomas Savery; James Watt.

SIR ISAAC NEWTON

English physicist and mathematician

Newton formulated the basic laws for the branch of physics known as mechanics, identified gravitation as the force that controls the motion of bodies in space and expressed it mathematically, and invented calculus independently of Gottfried Wilhelm Leibniz.
He also made lasting contributions to optics.

Born: December 25, 1642; Woolsthorpe, Lincolnshire, England
Died: March 20, 1727; London, England
Primary fields: Astronomy; chemistry; mathematics; physics
Primary inventions: Calculus; reflecting telescope

EARLY LIFE

Isaac Newton was born three months after his father died. He was born prematurely, and he is believed to have suffered from Asperger's syndrome, a form of autism. His mother, Hannah Ayscough, remarried when Newton was three years old, and she moved in with her new husband, the Reverend Barnabus Smith. The toddler was left to be cared for by his maternal grandmother. Ayscough had three children with her second husband, was widowed for the second time, and returned to Newton's birthplace after eight years.

Newton started school in the hamlet. When he was twelve, he went to King's College in Grantham, where he excelled in his studies. He was removed from school when he was seventeen and returned to Woolsthorpe. His mother wanted him to become a farmer, but Newton did not like farming; in fact, he was not good at it. Henry Stokes, a headmaster at King's College, convinced Newton's mother to send him back to the college to complete his studies. Newton did so, completed his work brilliantly, and was admitted to Trinity College at the age of nineteen, in June, 1661. Newton's mother still wanted him to devote his life to farming, but his maternal uncle, a clergyman who had attended Cambridge University, persuaded her to send Newton to the university. He was granted financial assistance for three years because he was a student with limited means. Such students were known as "sizars"; they earned money by serving the faculty and the wealthy students of the college. In 1664, he was elected a scholar, guaranteeing him four years of financial support. He obtained his degree in August, 1665, but the university was closed for about a year shortly after that because of concerns about the great plague. As a result, Newton went back to Woolsthorpe, where he continued his scientific work on calculus, optics, and universal gravitation.

LIFE'S WORK

Newton discovered the generalized binomial theorem and started working on calculus, although he would not publish this work until 1693. On July 5, 1687, he published a three-volume work entitled *Philosophiae naturalis principia mathematica* (*The Mathematical Principles of Natural Philosophy*, 1729). This title is usually abbreviated as *Principia*. The work was prepared during the 1665-1666 period, while Newton was in Woolsthorpe. It contains Newton's laws of motion, the law of universal gravitation, and a derivation of Johannes Kepler's laws for the motion of the planets.

Starting about 1668, Newton studied optics and discovered that the phenomenon of color had mathematical patterns that could be measured. He found that white light was a mixture of colored rays that manifested in the

Sir Isaac Newton. (Library of Congress) color spectrum, as exemplified by the rainbow. He also postulated that light consisted of streams of tiny particles. However, when he expressed his ideas in public in 1672 and 1675, he encountered hostile opposition. The reason was that his views on the nature of light were contradicted by the then accepted notions that considered colors to be modified, but distinct, versions of white light.

Newton formulated a theory of sound, but the speed he derived was too low and did not agree with his experimental results. This discrepancy was due to the fact that the concept of propagation without heat loss, the so-called adiabatic propagation, had not been proposed yet, and, hence, he did not take the heat capacities of air into account. Newton believed that matter consisted of different arrangements of atoms and devoted much time to the study of alchemy later in his life. While his burial place was being moved, exhumation revealed that Newton's remains contained large quantities of mercury. It is speculated that this was due to his alchemical experiments.

Newton was sensitive to criticism of his work and did not want to publish it. Indeed, he had many contemporary critics; among them were Christiaan Huygens (1629-1695) and Edme Mariotte (1620-1684). That may be why he held onto *Principia* for twenty years before publishing it, and why he waited until Huygens and Mariotte were dead before publishing *Opticks* in 1704. Newton's friends recognized his genius, and their persistent support and encouragement made it possible for Newton to publish his work and achieve recognition. His friend and mentor Isaac Barrow helped communicate Newton's discoveries to the mathematics community of London. Another friend, the English astronomer Edmond Halley, was the one who finally persuaded Newton to publish *Principia*.

Despite the criticism and the controversies, Newton's work was well received, even in his lifetime, and he was

CALCULUS

Sir Isaac Newton invented the method of "fluxions," which is known today as infinitesimal calculus. This mathematical process would prove to have many practical uses. For example, consider an empty bowl on a weight scale in which one drops coins one at a time. The total amount of money collected would not change continuously with time; rather, it would do so in "jumps" that represent the value of the coins added. If one pours water instead of coins into the bowl, the total weight would change continuously.

The mathematical techniques that are needed to determine the rates of changes in these two cases are very different. In the case of coins, the changes are finite; one could use a stopwatch to measure the time increment between two consecutive coin drops and a weight scale to register the change in the weight of the bowl over that time interval. Dividing the change in weight by the increment of time would give an estimate for the time rate of change of the weight over that interval. In the case of water, the changes are infinitesimal, however. Here, to perform a similar operation, one would need to imagine the existence of very small amounts of water being poured into the bowl over very tiny time intervals and subsequently take their ratios. How does one do this? Differential calculus teaches how to determine such ratios, and integral calculus shows how to backtrack. That is, if one knows what the ratio of two infinitesimal quantities is equal to, one can determine one of the quantities in terms of the other. Prior to the invention of calculus by Newton, no one knew how to determine the changes of quantities that vary continuously. Calculus is used extensively in modern science and engineering.

Although Newton did his work on calculus in 1666 and shared it with friends and colleagues, he would not publish it until 1693. The German mathematician Gottfried Wilhelm Leibniz (1646-1716) also worked on calculus and published his work in 1684. This nine-year difference in publication dates led to a bitter dispute between supporters of Newton and those of Leibniz regarding who should get historical credit for the invention of calculus. Members of the Royal Academy, of which Newton was a member, officially accused Leibniz of plagiarism in 1699, claiming, correctly, that Leibniz had seen Newton's papers when the former visited London in 1676. Friends of Leibniz thought it was exactly the opposite, claiming, correctly, that Leibniz had not taken notice of Newton's work on this subject. Leibniz died before the dispute was settled, and these tensions lasted about a century. Today, however, it is agreed that Newton and Leibniz invented calculus independently. However, that does not mean that the agreement led to a tie: Newton is given credit for having invented calculus before Leibniz, and Leibniz is given credit for having published his work before Newton's. Being reticent and late to publish his work caused Newton grief in life, modest loss of credit after death, and considerable stress and strain on his friends and foes alike.

recognized for it. He was elected a fellow of Trinity College in 1667 and Lucasian Professor of Mathematics in 1669. He became a fellow of the Royal Society of London in 1672, its president in 1703, and held that position for twenty-four years (1703-1727). Unfortunately, Newton suffered a mental breakdown between 1675 and 1679. He was appointed warden of the British Mint in 1695 and was knighted by Queen Anne in 1705.

Newton is still being honored for his work today. The Newton crater, a lunar feature, was named for him by American scientists. Rue Newton, located in the sixteenth arrondissement of Paris, is named for him. In physics, the laws of mechanics are named for him, and the standard unit of force is called the Newton: one pound-force is equal to 4.444 Newtons.

IMPACT

Specialists in the history of science believe that Newton contributed more to the development of science than any other individual in history. His work is thought to have ushered in the Age of Reason. There are three major reasons for this: First, Newton produced a scheme that helped humankind understand how the universe worked; that scheme far surpassed those that preceded it in intuitiveness, consistency, elegance, universality, and mathematical predictability. Second, in the process of devising his scheme, he developed the scientific method by formulating four rules of investigation that were revolutionary, concise, and universal—where "universal" means that, unlike the methods that preceded Newton's, his applied to all branches of science. Last, Newton not only outlined his rules for reasoning but also described how they might be applied to the solution of a given problem, and he actually applied them with great success to formulate some universal laws of nature. The method he invented was more scientifically based than the philosophical approaches of Aristotle (384-322 B.C.E.) and Thomas Aquinas (1225-1274).

When it comes to the development of modern science, Newton is considered to be the most important individual contributor. His ideas form the basis of modern technological civilization. His principles, although originally conceived for the physical sciences, were applied to the social sciences and influenced, for example, the economic theories of Adam Smith (1723-1790).

—*Josué Njock Libii*

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See also: Charles Babbage; Roger Bacon; Robert Wilhelm Bunsen; John Campbell; Albert Einstein; Philip Emeagwali; Galileo; James Gregory; Otto von Guericke; Joseph Henry; Christiaan Huygens; Zacharias Janssen; Dean Kamen; Gottfried Wilhelm Leibniz; Hans Lippershey; Pieter van Musschenbroek; John T. Thompson; Alessandro Volta; An Wang.

NICÉPHORE NIÉPCE

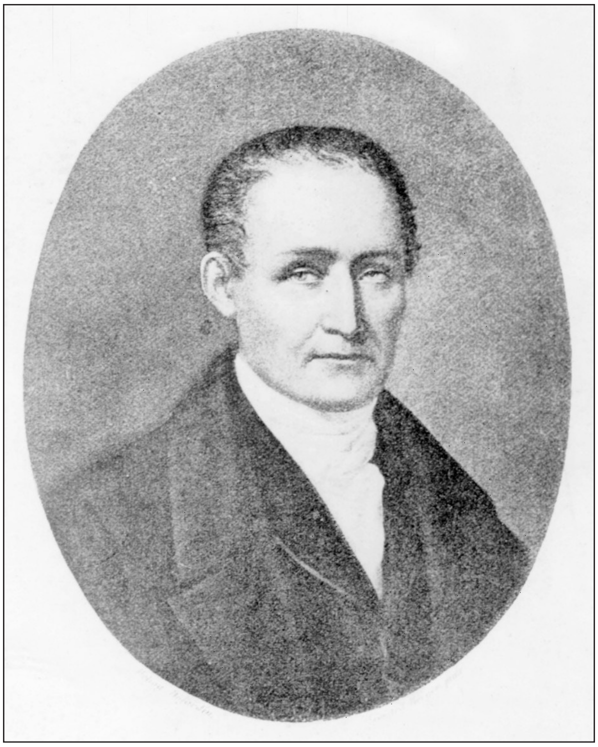
French engineer

The invention of photography by Niépce made possible the pictorial preservation of the life and experiences of the individual regardless of social class. It also enabled people to see actual images of places, events and notable things which they would otherwise never have been able to view.

Born: March 7, 1765; Chalon-sur-Saône, France
Died: July 5, 1833; Chalon-sur-Saône, France
Also known as: Joseph-Nicéphore Niépce (full name)
Primary field: Photography
Primary invention: Photography

EARLY LIFE

Joseph-Nicéphore Niépce (zhaw-zehf nee-say-fawr nyehps) was born on March 7, 1765, at Chalon-sur-Saône, France. His father was a lawyer, counsel to the king, and master of the Deposit and Consignment Office for Chalon-sur-Saône. He had one sister and two brothers. As a young man, he developed an interest in chemistry and physics. His father died in 1785, and his mother took charge of the family's business affairs. In 1786, he entered the Church as a member of the Oratorian Brothers at Angers. In 1788, he left the Oratorians and joined the Garde Nationale at Chalon-sur-Saône. At this time, he began to use the surname Nicéphore. In 1792, he enlisted in the French army and participated in campaigns in the south of France and in Sardinia. In 1794, he left the army. He was in Nice at the time, where he stayed and married; his son Isidore was born in 1795. Niépce's older brother Claude joined him there. In 1797, Niépce and his family traveled in Sardinia, and Claude accompanied them. It was during this trip that Niépce and Claude first conceived the idea of photography.



Nicéphore Niépce. (National Library of Medicine)

LIFE'S WORK

Upon their return to Nice, the two brothers began to work on inventing; however, it was not photography but rather the invention of an internal combustion engine that occupied them. In 1801, they were called back to Chalon-sur-Saône to take charge of the family's business affairs. They continued to work on their engine, which they named "Pyréolophore." They used it to power a two-meter-long model boat up the Saône. In 1807, they received a patent for it signed by Napoleon I.

In 1807, the government announced a competition for the invention of a new type of machine to replace the pumps at Marly that drew water from the Seine to the Palace of Versailles. From 1807 to 1809, the brothers were occupied with the project. They succeeded in constructing a hydraulic pump to provide the water. Unfortunately, they wished to improve their original pump and redesigned it several times. By the time they had finished it in 1809, Napoleon had commissioned Casimir Périer to build a steam engine for the operation of the pumps at Marly.

In 1811, because of the shortage of indigo caused by the Continental Blockade, Niépce and Claude began to work on the cultivation of woad as a substitute for indigo. Then, Claude left Chalons-sur-Saône, first going to Paris and then to England. The patent on their internal combustion engine was to expire the next year, and they wanted to promote it as much as possible while they still had the patent. Niépce and his brother corresponded by letters during Claude's absence. They were trying to find a different fuel for the internal combustion engine; eventually, by using lamp oil, they developed the principle of fuel injection.

Niépce was left with a lot of time to experiment and invent by himself, and he began to do research and experiments in photography. At the time, a camera obscura was used to create inverted images that were then traced by hand. Niépce did not have a hand steady enough to do this, so he needed to find a way to make the image permanent. He spent a considerable period of time attempting to find the right material to permanently fix the image. He experimented with lithography, then silver chloride, and finally bitumen. His first success came with bitumen. By 1818, he had managed to create an image that was fixed for three months without appreciable fading.

That year, Niépce began working on another type of invention he called a "velocipede," a bicycle without pedals. He made several modifications to it, including an adjustable seat. He was fascinated by his contraption and even thought of adding a motor to it, which he did not. He was often seen riding it on the roads of Saint-Loup-de-Varennes.

Niépce continued his experiments in photography. Starting in 1822, he was able to reproduce images by placing a design in contact with a piece of glass or metal coated with bitumen, then using etching techniques to engrave the image and print it on paper. He continued using and modifying this type of procedure until July of 1827, when he stopped because of repeated failures to engrave images of one color.

In December, 1827, on his way to England, he stopped in Paris for a while. There he made the acquaintance of inventor Louis Jacques Daguerre. Daguerre bought his lenses for his camera oscura from an optician named Vincent Chevalier, who was also Niépce's supplier. Daguerre obtained the address for Niépce from Chevalier and contacted him. Both of the men were experimenting to find a way to fix (keep from fading) the images produced in the camera obscura. They met again in 1828 and began to correspond with letters. In 1829, Niépce proposed that they create a partnership to develop what he called the "heliograph" (sun-drawing). Daguerre agreed, and they signed a contract that very year.

Together, they continued to experiment with bitumen but had little success. Next, they began trying various photosensitive residues. During 1831, Niépce, working alone, experimented with many different residues, but none worked well. Their greatest success came with the residue from essence of lavender. In June of 1832, Daguerre returned to Niépce's residence and together, using the distillate of lavender, they produced an image in less than eight hours of exposure time. Niépce named the process "physautotype."

PHOTOGRAPHY

Nicéphore Niépce had spent many years working with many different chemical processes in his attempt to fix the images captured in the camera obscura when he met Jacques Daguerre. The men collaborated and attempted to bleach brown bitumen and obtain positive images, but they failed. Then Daguerre discovered distillate of lavender, but he did not realize that it possessed photosensitivity. Niépce experimented with a number of photosensitive residues and distillates, none of which produced the desired results. Once again working with Daguerre, he tried using distillate of lavender oil, which they heated, and they discovered a photographic process that Niépce named "physautotype." Drying the oil turned it into a dark brown, tarlike substance. They put it into alcohol and poured the mixture onto a polished piece of silver. The alcohol evaporated, leaving a residue of white powder. Next, they exposed the piece of silver to light at the end of the camera obscura for approximately eight hours. Finally, the piece of silver was placed over a bowl containing white petroleum or lamp oil. The vapors revealed the image.

After Niépce's sudden death, Daguerre improved on the process and developed a slightly different process that he called the "daguerreotype." When the daguerreotype was revealed to the public, it caused a sensation and made Daguerre famous. The daguerreotype became a success throughout the world and changed the way history and personal memories were preserved.

On July 5, 1833, Niépce died unexpectedly. Isidore replaced his father in the partnership according to the terms of the ten-year contract. However, Isidore did not have the expertise to reproduce Niépce's procedures. Daguerre started working in secret on a new process, using techniques he had learned from Niépce. He eventually developed a new photographic process called the "daguerreotype."

In 1835, Daguerre suggested to Isidore that they make the three photographic processes—heliography, physautotype, and daguerreotype—known publicly. Daguerre knew that only one of the processes could be used successfully in a commercial situation. Isidore was in favor of the proposal. Daguerre then suggested that they change the company name from "Niépce Daguerre" to "Daguerre and Isidore Niépce." In this way, Daguerre began to edge Niépce out and take full credit for the invention of photography. Next, Daguerre showed his procedures to François Arago, the perpetual secretary of the Académie des Sciences. Arago was so impressed with the invention that he insisted that the French government pay and make it available to everyone. His proposal was accepted. Daguerre and Isidore each received an annual stipend of 4,000 francs for life. Daguerre received an additional 2,000 francs for the diorama that he had created for the Paris Opéra in 1822.

On August 19, 1839, Arago revealed the three processes to the public in such a way that only Daguerre was brought to people's attention. Almost no mention was made of Niépce. Subsequently, the daguerreotype process was improved, and it was possible to make portraits. Shops opened all over Paris, then around France, then Europe, and finally the United States. Daguerre became world famous, while Niépce remained unknown.

Isidore was incensed at the neglect of his father and his achievements. In 1841, he published a book, *Historique de la découverte improprement nommée daguerréotype, précédé d'une notice sur son véritable inventeur feu M. Joseph-Nicéphore Niépce* (historical account of the discovery improperly named the daguerreotype, preceded by an account of its true inventor). Isidore gave vent to his anger against Daguerre, put forth a case for his father as the inventor of photography, and started a long suit against Daguerre. Eventually, Nicéphore Niépce was recognized as the inventor of photography.

IMPACT

Although Niépce and his brother Claude have received little credit for their discoveries and inventions, their contributions have been significant. The two brothers invented an internal combustion engine and a hydraulic pump, and they discovered the principle of fuel injection. The internal combustion engine, which produces a high power-to-weight ratio, plays a very important role in the production of transportation vehicles. It is the main engine used in automobiles, trucks, and boats and with certain modifications in trains and in aircraft. Internal combustion engines also power a wide variety of machinery. Fuel injection has become the primary fuel delivery system used in these engines. Hydraulic pumps, which produce and easily transfer large amounts of power, are widely used in tools and heavy equipment. Thus, although the brothers remain virtually unknown and their inventions have become part of technology by the intermediary of other inventors, their research has been important in the development of the inventions.

Niépce, working alone and then with Daguerre, totally revolutionized the way in which events and individuals were recorded for posterity. Before the discovery of photography, only written accounts or artistic renderings were available to record history and preserve physical images. Artistic reproduction of people and events was affordable for only a small segment of the population, but photography made it possible for everyone to have a pictorial record of his or her life. It also permitted people to see pictures of actual places they had never visited.

—*Shawncey Webb*

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See also: Louis Jacques Daguerre; Auguste and Louis Lumière.

ALFRED NOBEL

Swedish chemist and engineer

The world is reminded in the fall of every year of the legacy of the inventor of dynamite, Alfred Nobel. The international prizes given in his name for achievements in chemistry, economics, physics, medicine, literature, and peace are symbols of the very highest accomplishment in those areas.

Born: October 21, 1833; Stockholm, Sweden
Died: December 10, 1896; San Remo, Italy
Also known as: Alfred Bernhard Nobel (full name)
Primary fields: Chemistry; military technology and weaponry
Primary invention: Dynamite

EARLY LIFE

The third of four sons, Alfred Bernhard Nobel (noh-BEHL) was born at a time of economic distress for his family. His father suffered a string of misfortunes as a building contractor, declared bankruptcy, and then was forced to flee creditors. He went to Finland when Alfred was four years old and later to St. Petersburg, Russia, leaving Alfred's mother to support the family in Stockholm by running a small vegetable and dairy product store. Alfred started his education at the poorest neighborhood school. Despite the shaky health that would dog him all his life, he gained distinction there as a promising scholar. The family was finally reunited in St. Petersburg in 1842.

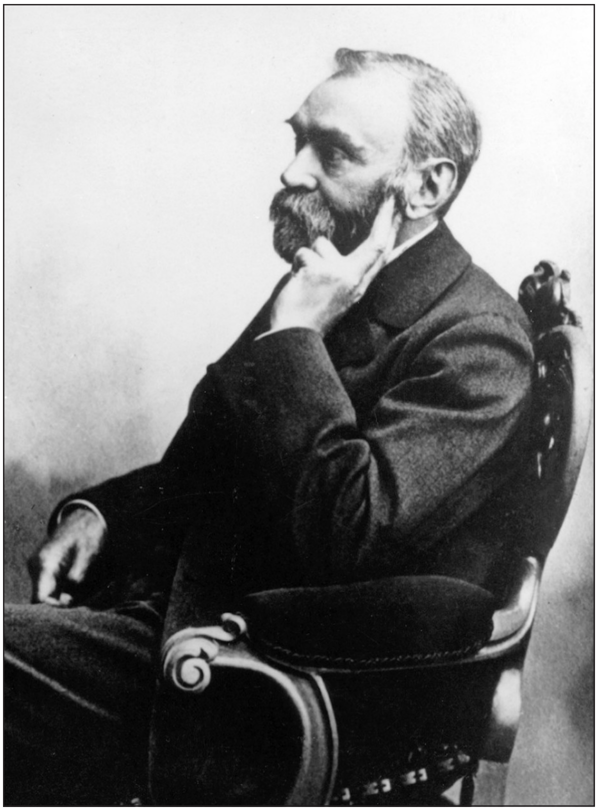
Alfred's father, Immanuel, had managed to reestablish himself in St. Petersburg in the business of manufacturing explosive mines, cannonballs, mortars, and components for steam engines. He had an inventive mind and held a number of patents, including one for the first central-heating system in Russia. His most important products were military, however, which he sold to the Russian war ministry. Business was excellent until Russia lost the Crimean War in 1856. The government defaulted on large debts to Immanuel's company, and he was forced to declare bankruptcy a second time.

The Nobel sons did not attend school in St. Petersburg, but they were provided with first-rate tutors and received an excellent education. Alfred seemed to be equally attracted to science and the arts as a youth. He expressed early interest in becoming a writer and eventually became fluent in five languages. As a kind of bribe to devote himself to more practical pursuits, Immanuel sent Alfred on a grand tour of Germany, France, Italy, and the United States in 1850.

The two crises he had observed in the financial fortunes of his father, however, were probably decisive in turning Alfred away from purely aesthetic endeavors. He devoted himself first to the family business, and then struck out on his own to establish one of the most innovative and successful enterprises in nineteenth century Europe.

LIFE'S WORK

Nobel's professional life was distinguished by the rare combination of inventive genius in the physical sciences and an equally remarkable flare for operating effectively in the highly competitive arena of international business. During his life, Nobel secured an amazing 355 patents in different countries in areas as diverse as aerial photography, blood transfusions, and prototypes for manufacturing artificial rubber and silk. The four major innovations for which he is best known, however, and which enabled him to build his immense personal fortune all had to do with explosives.



Alfred Nobel. (©The Nobel Foundation)

Dynamite

Black powder, or gunpowder, is a mixture of sulfur, charcoal, and saltpeter. It first appeared in China in the ninth century and arrived in Europe via the Islamic world in the fourteenth century. Few other inventions have had a greater impact on human society, and it was the only explosive in common use until the middle of the nineteenth century.

Alfred Nobel's dynamite began the process of replacing black powder, so that today it has only very limited recreational uses. Dynamite was the first high explosive developed that was safe enough to use for practical purposes. A high explosive does not burn like black power; it detonates and creates a supersonic shock wave. Nobel was able to develop dynamite through two critical breakthroughs in explosive technology.

Nobel's blasting cap was the key to detonating dynamite in a controlled way. He first used the old technology to set off the new one. He filled a small tube with black powder, attached a quick-match fuse, and submerged the device in the nitroglycerin to be detonated. This system worked, but it failed to create a shock wave strong enough to detonate large quantities of the primary explosive. Nobel then developed a blasting cap that was composed of mercury fulminate contained in a small copper capsule, which was more effective.

The precise composition of the primary explosive was the other problem to be solved before dynamite could be used safely. To stabilize it, Nobel tried mixing the nitroglycerin with numerous substances, such as powdered charcoal, sawdust, rock powder, brick dust, coal dust, and gypsum. The best one, however, and the most practical for marketing purposes, proved to be a local diatomaceous clay called kieselguhr. This substance mixed with nitroglycerin at a one-to-three ratio and together with a small amount of sodium carbonate formed Nobel's Safety Powder. This substance was then wrapped with paper into cylinders into which the blasting cap could be planted to become the familiar form of dynamite.

Ascanio Sobrero discovered nitroglycerin in 1846 by slowly pouring glycerol into a chilled mixture of nitric and sulfuric acids. The volatile concoction, which is about seven times more powerful than gunpowder, literally blew up in his face, however, wounding him seriously and scarring him for life. Sobrero decided that nitroglycerin was too dangerous for practical use. Nobel was not so sure. He began experimenting in the late 1850's with various ways to stabilize the liquid and ignite it in a controlled way.

Unfortunately, Nobel solved the ignition problem before the stabilization problem. The blasting cap developed by Nobel in the mid-1860's made possible the first innovation in explosive technology since gunpowder appeared in the fourteenth century in Europe. He began production and sales immediately, but the liquid nitroglycerin was still highly unstable, and many accidents and deaths occurred in the process of manufacturing, transporting, and storing it. One of the worst accidents killed Alfred's younger brother, Emil, and four other people when the Nobel factory in Heleneborg, Sweden, detonated and disappeared in September of 1864. Strict laws were passed in many countries making the transportation and use of this new explosive very difficult.

Nobel was forced to focus his creative intelligence on the stabilization problem and soon came up with a solution. He found a local clay that mixed well with nitroglycerin in a one-to-three ratio. The resulting powder was slightly less powerful than pure nitroglycerin but much more stable. This material was patented under the name of dynamite, or Nobel's Safety Powder, and went into production in 1867. Only eleven tons were produced that year, but by 1874 a number of factories in different countries produced some 3,120 tons. Massive engineering projects soon made possible by dynamite included the Gotthard Tunnel, the Canadian Pacific Railway, the Suez Canal, and the Panama Canal.

Under certain conditions, the liquid nitroglycerin could still separate from the powder and explode unpredictably, however, and dynamite could not be used effectively under water. These problems were solved when Nobel patented gelignite, or blasting gelatin, in 1875. The circumstances of the initial breakthrough illustrate the high level of awareness maintained by a truly inventive mind.

Reportedly, Nobel cut his finger one night while working in his laboratory in Paris and could not sleep because of the pain. He got up, put some collodion on it, and went back to bed. An hour later, he awoke again because the collodion coating had flaked off. He got up to make another application but began thinking about the chemical composition of this substance, which is created by dissolving cellulose nitrate in ether and alcohol. He began adding drops of nitroglycerin to it, and, in a few hours, he had produced gelignite. Three hundred separate experiments later, Nobel had perfected a powerful explosive material with the flexibility of rubber and the durability of leather.

The next major innovation credited to Nobel caused him a great deal of personal anguish because of the political problems that developed. Ballistite, which he patented in 1887, is a smokeless powder for use in large and small firearms. It is a combination of nitroglycerin, nitrocellulose, and camphor. Nobel developed it in his Paris laboratory, where he had been based for twenty years, so he offered the rights for his invention to the French government. The government refused his offer, believing that it already had a comparable product called Sarrau-Vieille, or Poudre B. Two years later, Nobel signed over his Italian patent rights to the Italian government and began supplying it with ballistite.

The French authorities were furious over Nobel's ballistite deal, and he was accused of espionage and treason in the press. His laboratory was searched by the police, and sample stock was seized. He was banned from using the French test ranges and not allowed to manufacture ballistite at his factory in Honfleur. Nobel's well-connected, longtime French partner, Paul Barbe, was unable to help him. In fact, Barbe was soon to be exposed as a swindler and committed suicide. Nobel was forced to leave his beloved Paris and relocate to San Remo, Italy.

Ballistite faired no better in Great Britain. Nobel had been in friendly communication about his work on this invention with Frederick Abel and James Dewar. They made some minor changes and patented a similar product there called cordite. Nobel lost the case in court over patent infringement, but in his opinion the judge referred to Abel as a dwarf standing on the shoulders of a giant.

Added to these disappointments in his professional life, Nobel's older brother died in 1888. He and Ludvig had been close professionally as well as personally. Then, he learned in 1891 that his mistress of fifteen years, Sophie Hess, was carrying the baby of another man, whom she eventually married. All these shocks combined to turn his thinking about the big issues of life in a new direction. He long had had qualms about the military uses of his inventions and the death and destruction they could cause, but in the last years of his life a plan took shape to address this issue concretely.

Impact

When Ludvig died, one of the French newspapers thought the deceased was his better-known brother, Alfred Nobel. The paper ran a scalding obituary calling Nobel a "merchant of death" who got rich on products that "maim and kill." Nobel was deeply hurt, but only slightly less vicious attacks had been coming at him since the early days when accidents with liquid nitroglycerin were common. They had a cumulative effect.

He had been friends for many years with a pioneering European pacifist named Bertha von Suttner, to whom he often expressed regret about the uses to which his inventions were occasionally put. In Paris in 1887, he outlined to her his ultimate defense. Nobel said that he would like to be able to create a substance or a machine with such a horrific capacity for mass annihilation that wars would become impossible forever. Unfortunately, even nuclear weapons so far have not abolished war in the way he envisioned, but perhaps this basic idea will yet prove correct.

To further the cause of peace, as well as science and the arts, which are closely related, Nobel established a foundation in his will for the purpose of awarding international prizes for the most outstanding accomplishments in five areas. The Royal Swedish Academy of Sciences was to decide on the winners in physics and chemistry. The Karolinska Institute would award the prize in medicine. The Swedish Academy would decide on the winner of the prize in literature. Finally, and most surprising, the Norwegian parliament was to make the decision about the winner of the Nobel Peace Prize.

At the time of his death, Nobel had assets in France, England, Germany, Scotland, Italy, Austria, Norway, and Russia, as well as Sweden. When these assets had been liquidated, a total of 31,225,000 Swedish crowns remained. Some of his heirs were not happy to receive only the minimum bequests required by Swedish law, but after settling with them and with Sophie Hess out of court, the Nobel Foundation was established on June 27, 1900. The original capital was invested, and every year the earnings are divided among the recipients of the various Nobel Prizes. The inventor of dynamite would seem to have atoned many times over for the destructive uses to which it sometimes has been put.

In fact, the military applications of dynamite were quite limited. It could not be used to pack ordnance because the heat of launching the shell would detonate the charge in the barrel of the firearm. Propulsion systems utilizing compressed air were developed in the late nineteenth century but never came into common use. Dynamite could only be used effectively for purposes of sabotage and terrorism. For example, there was a violent Irish nationalist paramilitary organization operating out of New York around this time, which was actually called the Dynamite Party. Then, shortly after Nobel's death, trinitrotoluene (TNT) became the gold standard of regular military explosives.

On the other hand, the immense and numerous engineering projects facilitated by the use of dynamite and other nitroglycerin-based explosives stand as monuments to Nobel's genius. They have sped the transportation of people and products around the world and vastly improved the quality of life for virtually everyone living in the twenty-first century. The international prizes awarded every year in his name are by far the most prestigious of their kind. It can only be hoped that these Nobel Prizes will eventually help to realize Nobel's dream of a world in which explosives are only used for constructive and peaceful purposes.

—*Steven Lehman*

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See also: J. Georg Bednorz; Sir James Dewar; Fritz Haber; Hudson Maxim.

ROBERT NORTON NOYCE

American electrical engineer

Noyce's development of the integrated circuit made possible the mass production of very complex computer circuitry, thus paving the way for the digital revolution. His subsequent leadership of the American semiconductor industry helped consolidate its preeminence.

Born: December 12, 1927; Burlington, Iowa
Died: June 30, 1990; Austin, Texas
Primary fields: Computer science; electronics and electrical engineering
Primary invention: Integrated circuit

EARLY LIFE

Robert Norton Noyce was born in Iowa to a Congregationalist minister. Although the position did not pay an enormous amount of money, the family was well enough off for Mrs. Noyce to be able to have a hospital birth, something still considered unusual at the time. For the next several years, the Noyce family moved from town to town as Reverend Noyce took work with various congregations before settling permanently in Grinnell, a small town west of Des Moines.

Young Robert showed an interest in science and technology from a very early age and was soon working various part-time jobs in order to buy such delights as a crystal radio kit. However, he was not the stereotypical nerd, fascinated with technology to the exclusion of all else. He also showed a striking aptitude for sports, which he turned to good use in some of his more daring and physical mechanical exploits such as building and flying a glider. With his slim, muscular build and good looks, he was also quite successful with the opposite sex.

However, while he was a student at Grinnell College, an adolescent lark nearly wrecked his promising career. Several young men in his dormitory took it upon themselves to throw a genuine Hawaiian luau, complete with a roast pig. It fell upon Robert and another strapping young athlete to acquire the pig, a feat they accomplished by stealing one from a nearby farmer's pen. Although the event was a success, Robert was subsequently struck with pangs of conscience and turned himself in as the thief. Only because of his father's standing as a local minister and the intercession of one of the professors did he avoid criminal proceedings. Instead, he was suspended for a semester; he used that time to work at a local insurance company and gain experience with the practical side of mathematics.

When he returned to Grinnell College, he learned about a fascinating new development, the transistor. Immediately, he perceived the breadth of possibilities represented by solid-state electronics and set his sights on graduate work at the Massachussetts Institute of Technology (MIT). After he completed his Ph.D. there, he took a position with Philco, a well-known manufacturer of radios and televisions.

LIFE'S WORK

The job at Philco put Noyce in the position to do real practical science and to become noted in wider circles through monographs and papers in technical journals. This work brought him to the attention of William Shockley, one of the coinventors of the transistor. Shockley had left Bell Laboratories to found his own company, Shockley Semiconductor Laboratory, and he was looking for top-flight talent to implement his new ideas for more sophisticated transistors. Noyce was delighted at the opportunity to work with the prominent physicist.

However, the shine soon wore off the job. Though Shockley was a brilliant physicist, when it came to personnel management he was an utter dunce. When he launched a full-scale sabotage investigation over a fragment of metal that turned out to be a pushpin that had lost its protective glass head, several engineers, including Noyce, decided they had had enough. This group, which Shockley would later condemn as the "Traitorous Eight," found venture capital from Fairchild Camera and Instrument and thus founded Fairchild Semiconductor just down the road from Shockley's company.

However, Fairchild's products were still all discrete transistors, which meant they needed to be soldered onto circuit boards in order to create useful electronic devices. While such transistors were fine for simple devices, in complex circuits it became likely that at least one solder would be faulty, rendering the entire circuit inoperable. This "tyranny of numbers" became the consuming problem for electrical engineers of the 1950's. Noyce hit upon the solution almost by accident, when Fairchild's patent attorney asked him to think of as many possible uses for a new fabrication method. Although the integrated circuit was a major breakthrough, Noyce's corporate bosses at Fairchild Camera and Instrument had little understanding of how to market it. Growing increasingly frustrated with the situation, Noyce and fellow "Traitorous Eight" member Gordon Moore left Fairchild to found Intel.

Robert Norton Noyce at his office at Fairchild Semiconductor with diagrams of semiconductors and microchips. (Time & Life Pictures/Getty Images)

In founding his own company, however, Noyce left the laboratory behind for good. The integrated circuit would be his last significant invention. Henceforth, he would be primarily an administrator, leading others such as Ted Hoff, who took the integrated circuit to the next step with the microprocessor. Noyce created a new corporate culture at Intel, with a relatively flat hierarchy. Although he was fiercely competitive toward other companies, he wanted to minimize internal competition, emphasizing that everyone at Intel was on the same team with the same goal. There were no executive privileges, even for himself. He had no office, just a cubicle with shoulder-high partitions, and he ate his lunches in the corporate lunchroom rather than in a private executive dining room. He parked in whatever spot happened to be available when he arrived each morning, and if he were to run late one morning, his name would be posted on the "late list" just like any other Intel employee.

By the 1980's, Noyce had largely moved away from

THE INTEGRATED CIRCUIT

When the transistor was first developed, it was hailed as a vast improvement over the vacuum tube. Its small size meant that it used much less power and produced much less heat, but its size also made it difficult to wire together into circuits. While a vacuum tube sat in a socket, a transistor had three tiny wire leads that had to be threaded through holes in the circuit board and soldered to the circuit traces with tiny beads of molten metal. This was a difficult, painstaking task, and no matter how careful the workers were, it was inevitable that at least a few solders would be faulty. This was an annoyance in relatively simple circuits such as a radio, but when one was building complex circuitry for telephone switching centers or computers, it became a major problem.

Throughout the 1950's, engineers sought the answer to this "tyranny of numbers." The most common solution was to make the parts even tinier, which only exacerbated the problem. The people assembling circuit boards then had to use tweezers to position the components and peer through magnifying glasses to solder them. Another solution was to make all the components the same size, with identical joining parts, so they would snap together like Tinkertoys.

Two men, Jack St. Clair Kilby of Texas Instruments and Robert Norton Noyce of Fairchild Semiconductor, hit upon the idea of making all the components from a single piece of silicon. Kilby started with the realization that all the necessary components could be made from silicon and need not be cut apart. As a result, when it came time to make a working integrated circuit, he made the necessary electrical connections with tiny wires stuck into the silicon. However, while this worked for a prototype in a proof-of-concept demonstration, as a commercial product that integrated circuit would be no great improvement over discrete transistors.

By contrast, Noyce was trying to think of as many possible ways to use the planar process, a technique by which transistors were deposited on a piece of silicon as flat structures. Fairchild's patent attorney wanted to write the patent as broadly as possible in order to include as many money-making products as possible. While brainstorming, Noyce realized that one could also lay down connections within the transistors and between them. That realization led to the idea of making all the components and connections for an entire circuit from a single piece of silicon and only having leads where it needed to communicate with the outside world.

Since Noyce's idea lent itself to mass reproduction through the photolithographic process, Fairchild was soon producing commercial integrated circuits. Although the earliest integrated circuits had fewer than a dozen components, improvements in etching techniques enabled a rapid increase in the number of transistors on a chip of a given size, and a rapid reduction in the price of existing chip designs, a principle often referred to as Moore's law (named for Noyce's business partner Gordon Moore). The next logical development was to put the circuitry of a computer's central processing unit (CPU) on a single chip, creating the programmable microprocessor.

the day-to-day administration of Intel to address larger issues in the semiconductor industry. Seeing weaknesses in key parts of the industry, he began to push for a consortium that would help draw together the various companies to protect the interests of the industry. Thus, SEMATECH was born. When he was made its head, he had to leave his beloved Silicon Valley and move to Austin, Texas. He lived there for four years, until his sudden death of a heart attack in 1990 at the age of sixty-two. As a result, he missed his opportunity to win his share of a Nobel Prize in Physics alongside Jack St. Clair Kilby in 2000.

IMPACT

In addition to his work with the integrated circuit, the foundation of the digital revolution, Noyce was critical in the development of California's Santa Clara Valley as a hub of technology innovation. Twice leaving employers to found new companies, he set a pattern that would mark the culture of Silicon Valley, showing that there was little disgrace attached to frequent job changes and that people could easily find venture capital to start their own companies. The culture that Noyce created was absolutely essential to the risk-taking that enabled the rapid growth of the computer industry. In addition, the relatively flat corporate hierarchy he fostered at Intel paved the way for the even more relaxed jeans-and-sneakers culture of the next generation of Silicon Valley companies, including Apple and Google.

—*Leigh Husband Kimmel*

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See also: John Bardeen; Bill Gates; Ted Hoff; Steve Jobs; Jack St. Clair Kilby; William Shockley.

VICTOR LEATON OCHOA

Mexican American engineer

Ochoa invented an airplane with collapsible wings, called the Ochoaplane, and several mechanical and electrical devices, such as an adjustable wrench, a windmill, and an electric brake for streetcars.

Born: 1850; Ojinaga, Mexico
Died: c. 1945; possibly Sinaloa, Mexico
Primary fields: Aeronautics and aerospace technology; mechanical engineering
Primary inventions: Ochoaplane; electricity-generating windmill

EARLY LIFE

Victor Leaton Ochoa (oh-CHOH-uh) was born in Ojinaga, Mexico, to Juan and Isabel Leaton Ochoa. His mother was also known as Elizabeth Leaton before her marriage. She was the daughter of Ben Leaton, a prominent figure in the Presidio, Texas, area (across the Rio Grande River from Ojinaga). Ben Leaton remodeled an old Spanish mission, located about three miles east of Presidio, into a fort and trading post. It later became known as Fort Leaton, now a Texas State Historic Site.

Juan and Isabel Ochoa had five children. Victor was the firstborn; the others were Lucia, Esteban, Eduardo, and Enrique. Juan was collector of the Port of Presidio Del Norte. He also owned a large lumber mill in Fort Davis. According to a family story, Juan was attacked by American Indians while he was harvesting timber. His sons Victor and Esteban were with him and managed to get him loaded onto a wagon and taken back to Fort Leaton, where he died. After Juan's death, Isabel married Frank Shirley.

Victor Ochoa lived in the United States in various places for most of his life. He became a U.S. citizen in 1889. Ochoa did not begin inventing until late in his life. He was more than fifty years old when his first U.S. patent was issued in 1903. Before that, he led an active, colorful life in Texas, the New Mexico Territory, and Mexico.

LIFE'S WORK

Ochoa married Juana Sanchez and had three children: Sam, Stella, and Isabel. For at least part of Ochoa's married life with Juana, the family lived in Las Vegas, New Mexico Territory, where Juana was murdered by assassins hired to kill her husband, who had been uncovering corruption in the city as a newspaper editor. *New York Times* articles from 1893 and 1895 report that Ochoa was editor of the *Hispano Americano*, a daily newspaper in El Paso, Texas.

In addition to being an inventor and newspaper editor, Ochoa was a Texas Mexican activist and a supporter of the Mexican Revolution against President Porfirio Díaz. In the early 1890's, Ochoa helped organize La Unión Occidental Mexicana, a community-based organization that served as a social and political forum for Texas Mexicans. He was arrested in the United States in April, 1895, for his revolutionary activities, because Mexico was at peace with the United States. He was sentenced to two years in a penitentiary in Brooklyn, New York.

Victor's second wife was Amanda Cole, granddaughter of Thomas Cole, an American painter. Victor and Amanda had two children, Esteban Leaton and Lucia.

Ochoa's earliest U.S. patent was issued on January 13, 1903 (U.S. Patent number 718,508), for a reversible electric motor. Ochoa was residing in Peekskill, New York, at this time. In 1906, he received a patent for a fountain pen and sold the patent to the Waterman Pen Company. In 1907, he was issued three U.S. patents. The first was for a pen and pencil clip, and he sold the patent to the American Pen and Pencil Company. The other two patents were for a magnetic brake for streetcars and an improvement to this brake. Ochoa sold these patents to the American Brake Company in Seattle.

During 1908-1911, Ochoa designed the Ochoaplane, an airplane with collapsible wings that allowed for easy storage in a garage or barn. The machine had a framework of steel spring and steel tubing, put together so that it could be folded by working a lever. It had a canvas covering and was about twenty-six feet wide and six feet long. It was powered by a six-horsepower motor and weighed about 250 pounds. Ochoa had been working on this airplane for more than twenty years. It was never patented in the United States, and there is no evidence of its widespread success. During this time, Ochoa is reported to have been the president of the International Airship Company, based in Paterson, New Jersey.

In 1919, Ochoa was issued a patent for a windmill with a rotor, which rotated on a vertical shaft rather than the typical disk rotating on a horizontal shaft, which was used in water-pumping windmills. A half interest in the patent was assigned to Leigh Clark of El Paso, where Ochoa was residing at the time. Ochoa's last two U.S. patents were issued in 1922 and 1923. They were for an adjustable wrench and an improvement to the invention. The patent of May 8, 1923, was assigned to the Ochoa Tool and Machine Company, a Delaware corporation.

Ochoa is believed to have died in 1945 in Sinaloa, Mexico, but the exact date and details are not known. Included in a Smithsonian Institution collection of Ochoa's papers is a letter he wrote to his son Stephen dated June 7, 1945.

IMPACT

Ochoa was an active Hispanic American inventor in the early twentieth century. He designed several devices between 1903 and 1923 and sold the rights to several of them to companies. He formed two companies: the International Airship Company, which produced the Ochoaplane, and the Ochoa Tool and Machine Company, which manufactured his adjustable wrench.

Ochoa was a prominent man in his time, having served as editor of at least two Spanish-language newspapers, in Las Vegas and El Paso. He was also active in Hispanic American affairs in the Southwest. He lived part of his life in New York and New Jersey and was said to be a friend of President Theodore Roosevelt.

Ochoa received a patent in 1919 for a simple windmill in which the wind directly turned a vertical shaft. Typical windmills, used for pumping water out of the ground, used a horizontal shaft turned by the wind; the horizontal rotating shaft then had to be converted to up-and-down reciprocating action to drive the pump. Ochoa also proposed use of his windmill to generate electricity, a concept that gained momentum in the early twenty-first century.

—*Harlan H. Bengtson*

IMPROVEMENTS TO THE WINDMILL

Victor Leaton Ochoa's windmill design was simpler than the typical windmills of the early twentieth century, which were used to pump water from the ground. Ochoa claimed that his windmills cost only one-fifth as much as ordinary windmills to put up. He suggested attaching a dynamo and storage batteries to the windmill to provide electric power to a building.

Ochoa was issued a patent on October 21, 1919, for his windmill design. It had a vertical shaft turned directly by the wind, which blew on rectangular vanes mounted at the top of the shaft. His design also included a means of preventing the speed of rotation from becoming excessive in very high winds—by moving some of the vanes into an inoperative position during excessive wind speed.

The most widely used windmill design in Ochoa's time is still in use today for pumping water from the ground in remote locations. This design utilizes a fan-type wheel mounted on a horizontal shaft at the top of the windmill. The wheel turns as a result of wind blowing on it from a direction perpendicular to the plane of the wheel. The wheel is kept facing into the wind by a weathervane mounted perpendicular to the wheel. All of this produces a rotating horizontal shaft. A "windmill motor" mounted at the top of the windmill converts the energy of the rotating shaft to a reciprocating motion, which moves a shaft up and down. This shaft goes from the top of the windmill down into the well at its base. The shaft moves a piston up and down in a pump placed in the water at the bottom of the well. The piston together with a one-way valve brings a column of water up from the bottom of the well to a tank, pond, or some use at the surface.

With Ochoa's simple design, which used a rotating vertical shaft at the base of the windmill to run a dynamo to generate electricity, there would be no need to have the windmill "facing into the wind." The rotation of the vertical shaft would be produced directly without the need for a windmill motor at the top of the windmill. Ochoa stated that one of his windmills with vanes seven feet long could produce enough electrical power to light a building and provide all other necessary power. Of course, "all other necessary power" for a building at that time was significantly less than it would be today.

Ochoa proposed the use of his windmill/generator for areas outside large cities. However, centrally generated electric power eventually became available over most of the United States, and local generation of electric power for homes never came into widespread use. In the early twenty-first century, there has been a resurgence of interest in wind power for both centralized and home-based generation of electricity. Perhaps Ochoa's windmill was ahead of its time.

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See also: George Cayley; Étienne Lenoir; Wilbur and Orville Wright.

HANS JOACHIM PABST VON OHAIN

German mechanical engineer

Von Ohain was the first to design and run a turbojet engine as well as the first designer whose engine successfully powered a jet aircraft.

Born: December 14, 1911; Dessau, Germany
Died: March 13, 1998; Melbourne, Florida
Primary fields: Aeronautics and aerospace technology; mechanical engineering
Primary invention: Jet engine

EARLY LIFE

Hans Joachim Pabst von Ohain (OH-hayn) was born into an upper-class German family on December 14, 1911. His father, Wolfe Pabst von Ohain, was a career military officer. His mother, Katherina Nagel, came from a wealthy farm family. At an early age, the young man displayed an interest and ability in science. When Hans was thirteen years old, the family moved to Berlin, where he attended Arndt-Gymnasium in Dahlem in preparation for the university. At Arndt, he proved to be only a mediocre student until he was exposed to Albert Einstein's theory of relativity. Einstein's ideas excited him, and he developed an intense interest in mathematics and began to excel in both that subject and physics. He then attended Georg-August University at Göttingen, where he specialized in physics, thermodynamics, and aerodynamics.

He was very successful in his university studies and completed the seven-year doctoral curriculum in four years. His Ph.D. was awarded on November 1, 1935, in physics, with minors in mathematics, aeromechanics, and aerodynamics. His doctoral dissertation concerned "An Interference Light Relay for White Light." At the same time that he was researching and writing his dissertation, he became interested in aircraft propulsion systems. He had flown gliders and was fascinated with what he called the "elegance of flight." When he experienced his first powered flight aboard a Junkers tri-motor aircraft, he was appalled at the noise, vibration, and discomfort associated with powered flight. He felt that the elegance he had experienced in the gliders was destroyed by the engines. It was at this point that he began to examine alternative sources of power, and this led him to design his turbojet engine.

LIFE'S WORK

Von Ohain began work on his engine in 1934 largely with money supplied by his maternal grandmother. He received a patent on November 10, 1935, which was classified as secret. He estimated that an aircraft powered by this engine could operate at approximately five hundred miles per hour. One major concern was the excessively high estimated fuel consumption, a problem that was also being addressed by Frank Whittle in England. After a year of calculating and designing, von Ohain was convinced that his design was practical. He decided to construct a test model, and he employed his car mechanic, Max Hahn, to build it. At each setback the team experienced, von Ohain would design an alternative that improved on the original design and Hahn would build it. Interestingly, even though Hahn agreed to build the engine, he was convinced that it would never work. It was this model that von Ohain presented to Ernst Heinkel, who agreed to finance the project. Von Ohain proceeded to build a test engine fueled by hydrogen to minimize combustion problems.

While von Ohain was attending the university, the National Socialist German Workers' Party came to power. Von Ohain was largely apolitical during his university career and avoided involvement as much as was possible. He went so far as to resign his membership in the university soaring club when the National Socialists took it over and politicized it. Ironically, with the success of his proof-of-concept hydrogen engine, his work became known to the Air Ministry. As the newly appointed director of turbine engine development for the Heinkel

Aircraft Company, he was faced with the responsibility of dealing with party officials in the ministry. The aircraft industry was in the center of the military buildup for the approaching World War II. Von Ohain and Heinkel managed to keep most of their work secret, and even the Air Ministry was largely unaware of their progress. Through Heinkel's protection, von Ohain was never forced to join the Nazi Party.

The Heinkel factory designed and built a special test-bed aircraft for a flyable version of von Ohain's engine. This was the Heinkel 178, an experimental design not intended for production. Von Ohain's latest version of his engine, the He S3B, was installed in the aircraft. This new version developed one thousand pounds of thrust and had been test run for ten hours. The first jet-powered aircraft successfully flew on August 27, 1939, only three years after the project was initiated. Von Ohain's next design was shelved in favor of developing a multistage axial-flow engine known as the He S30. This engine proved to be unsuccessful, and von Ohain returned to his centrifugal-flow design and produced the He S8A, which developed thirteen hundred pounds of thrust. Two of the engines were mounted under the wings of the Heinkel He 280 aircraft. This was the world's first jet fighter, and it flew on March 30, 1941.

As the war turned against Germany and the Allied bombing increased, the aircraft factories became prime targets. Materials became scarce, and it was not until April, 1942, that the long-delayed He S30 axial-flow engine first ran. The Air Ministry decided that the Messerschmitt Me 262 powered by the Jumo 004 engine would be the world's first mass-produced jet aircraft, not the Heinkel He 280. Production and development of the He S8 and He S30 series were canceled, and Heinkel was ordered to cease production of jet-powered aircraft. Although Heinkel and von Ohain were again contracted to develop a second-generation turbojet, the He S011, the final collapse of Germany intervened. This engine was the most powerful turbojet engine designed to date, but only nine examples were built and bench-tested. It was never mass-produced. Thus, the advantages gained by developing von Ohain's proven design were lost, and no engine of his was ever put into production.

The Allied occupation resulted in von Ohain being questioned by a team of American intelligence experts. His name appeared on a list of high-priority German scientists who were to be brought to the United States. In 1947, under an operation known as Project Paperclip, von Ohain was invited to emigrate to the United States. He readily accepted and arrived in February of 1947 at Wright-Patterson Air Force Base, where he began work

THE TURBOJET ENGINE

The engine that powered the first jet aircraft was Hans Joachim Pabst von Ohain's Heinkel S3B. It operated on the principle of ingesting large quantities of air, compressing that air, and introducing fuel. This fuel-air mixture was then ignited, and the accelerating gases passed through a turbine wheel. The gases not used to drive the turbine-compressor unit were directed rearward in the form of thrust. The S3B incorporated a two-stage centrifugal compressor. The idea of a two-stage compressor reduced the stresses required to increase the air pressure to the desired level because the differential between the inlet and outlet pressure at each of the stages was considerably less than that imposed on a single-stage compressor, which would require a large differential to achieve the same pressure increase. This compressed air was then directed through ducts to the bars where fuel was injected. A spark plug ignited the gases, and these hot gases accelerated past a number of stationary vanes out the single combustion chamber. The gases exiting the combustion chamber were directed into the single-stage turbine wheel, which turned the compressor mounted on the same shaft. The design ensured that only the minimum amount of energy required was used to turn the compressor, thus maximizing the amount used as thrust. Ironically, none of von Ohain's designs reached the production stage, as the German government decided to produce designs by other manufacturers.

Von Ohain's final design under the Heinkel Aircraft Company, the He S011, fell into the hands of the U.S. military during the occupation of Germany. This was a true axial-flow design with five stages of compression and a two-stage turbine. While this engine had never reached the production stage prior to the fall of Germany, it was by far the most advanced turbojet design up to that time and closely resembled many modern turbojet engines. The original engine produced 2,860 pounds of thrust, and von Ohain estimated that it could grow to 3,500 pounds with a potential pressure ratio of eight to one. These were values that had been unachievable up to that time. Von Ohain and this engine design were brought to the United States, where his work continued for many years and resulted in a number of successful innovations in jet-engine technology. Much of the technology used in today's modern jet engines is a result of the genius of von Ohain.

for the Air Force and continued his research for more than thirty years. He continued to develop improvements to the turbine engine and propulsion technology, and he eventually became the chief of the Aerospace Research Laboratory and was chosen as the chief scientist in 1964. He served in that capacity until 1975, when the Aerospace Research Laboratory was disbanded, and he became the chief scientist of the Aero Propulsion Laboratory. He retired in January, 1979, but continued to work part-time for the University of Dayton Research Institute for another ten years. Von Ohain died on March 13, 1998, in Melbourne, Florida.

IMPACT

Von Ohain was blessed with a very original mind. He was able to analyze a problem and develop a solution based almost entirely on his own insight. He readily admitted that he did not research previous work on the turbojet idea, and he felt that this freed him from the typical limitations and constraints to which most researchers are subject. In his work on the turbojet engine, he identified the problems and then logically addressed them. When one of his concepts proved unworkable or inefficient, he simply altered it or developed an entirely new solution. While he became an outstanding engineer, he really had little experience in the actual manufacturing process. He addressed this shortcoming by surrounding himself with competent assistants to whom he always gave credit for their efforts.

The limitations of piston-powered, propeller-driven aircraft were widely known prior to von Ohain's work. He arrived at what was to become his life work quite by accident. His horror at the discomfort of his first powered aircraft flight led him on a search to reestablish what he termed the "elegance of flight." The idea of a turbine-powered engine that would reduce vibration, operate at higher altitude, and increase cruising speeds was his solution. After leaving Germany, he continued his work to design and improve the turbojet engine for many years. It was not only his ability as an engineer that set him apart but also his leadership skills. He had the talent to match personnel and projects based on the demands of the project and the specific ability of the individual. He and his team were responsible for a number of design improvements to jet engines, and he personally was awarded more than thirty patents ranging from the "Jet Wing with Multiple Thrust Augmentors" to his last, the "Water Craft with a Hydrofoil-Bladed Wheel Assembly." These patents were in addition to the fifty German patents he was awarded under Heinkel Aircraft between 1935 and 1945. Von Ohain was a man of tremendous vision and energy, and the success of modern jet-engine technology can be traced back directly to this vision and energy.

—*Ronald J. Ferrara*

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See also: Wernher von Braun; Bill Lear; Sir Frank Whittle.

RANSOM ELI OLDS

American automobile manufacturer

By building his two steam-powered carriages and then a gasoline-powered vehicle, Olds was able to find practical solutions to the problems that stood in the way of the development of the automobile. As a manufacturer, Olds was just as innovative. By outsourcing parts and organizing an assembly line, he revolutionized the production process.

Born: June 3, 1864; Geneva, Ohio
Died: August 26, 1950; Lansing, Michigan
Also known as: R. E. Olds
Primary fields: Automotive technology; manufacturing
Primary invention: Olds horseless carriage

EARLY LIFE

Ransom Eli Olds was the fourth son and youngest of five children born to Pliny Fisk Olds—the son of Jason Olds, a Congregational minister who had come from Massachusetts to Ohio as a missionary—and his wife Sarah Whipple Olds. At the time of Ransom's birth, Pliny still owned the blacksmith and machine shop in Geneva, Ohio, that he had established ten years before. Even as a young child, Ransom spent much of his time in the shop, sometimes making toys with the help of his older brothers. Evidently the business was not doing well, for in 1870 Pliny traded it for a house in Cleveland, Ohio, where he became superintendent at an ironworks. Ransom started school in Cleveland. Though he was shy, he must have been appealing, for at the end of the year his teacher presented him with a book. However, the boy's happiest memories were of his visits to the ironworks, which he found fascinating.

After four years in Cleveland, Pliny acquired a farm at nearby Parma. Ransom, now ten, went to a country school a mile from his home. At lunchtime, he avoided the boys his age, whom he found too rough, and played with the girls instead. Though he enjoyed helping his father repair tools in his small blacksmith shop, Ransom developed an aversion to farming and especially to the smell of horses, which he later said motivated him to develop a horseless carriage.

In 1878, Pliny gave up farming and went back to Cleveland to work as a pattern maker, taking Ransom with him so that the boy could go to school there. In 1880, Pliny managed to trade his farm for property in Lansing, Michigan, and the family was reunited. In 1880, Pliny and his son Wallace opened P. F. Olds and Son, where they repaired machinery and manufactured steam engines. Ransom Olds attended high school briefly, dropping out after tenth grade.

LIFE'S WORK

From 1882 to 1883, Ransom Olds took courses at Bartlett's Business College so that he could attend to the bookkeeping at his father's shop. In 1885, Olds bought out his brother Wallace and became his father's partner. One of Olds's inventions, a steam engine powered by a gasoline burner, became their most profitable product. Pliny Olds was dubious about his son's next project, a three-wheel horseless carriage powered by a similar device. Nevertheless, it was completed in 1887. A four-wheel horseless carriage followed five years later.

Meanwhile, Olds had begun courting Metta Ursula Woodward, a quiet, high-principled girl from Pinckney, Michigan. On June 5, 1889, they were married. Eventually they had four children, but only the first two, Gladys Marguerite and Bernice Estelle, survived infancy. Metta is credited with persuading Olds to become active in the Baptist Church and involved in community activities.

Like other early automakers, Olds experimented with battery-powered vehicles, but after seeing the internal combustion engines displayed at the Chicago World's Fair in 1893, he decided to switch over to gasoline power. By 1896, Olds had developed his own internal combustion engine, patented it, and turned out a gasoline-powered horseless carriage, which in his patent application he called an automobile. He then divided the family enterprise into the Olds Gasoline Engine Works and the Olds Motor Vehicle Company. It soon became evident that he would need outside financing for his motor vehicle operation, which was seen as a risky venture. In 1899, Olds gave up financial control of his company, renamed his firm the Olds Motor Works, and moved most of the operations to a large, new plant in Detroit. Among the models of what now had the brand name of Oldsmobile was a simple, open vehicle with a curved dash, designed for use as a runabout, that could be sold for the phenomenally low price of $650.

When production on the curved-dash model began in 1901, there were buyers waiting. Then, on March 9, the new plant was destroyed by fire. Fortunately, since he was already obtaining parts from a number of suppliers,

THE OLDS HORSELESS CARRIAGE

In 1887, Ransom Eli Olds invented and constructed his first horseless carriage. It resembled a child's tricycle, with two large, steel-tired wheels in the back and a third, smaller one in front, which was attached to a fork. Olds reasoned that this configuration would make the vehicle easier to steer. Behind the front wheel and between the two back wheels was a boxlike structure, with a single seat hollowed out for the driver. Olds used a long rod attached to the front wheel as a tiller. The vehicle was powered by a one-horse-power engine located in a box behind the seat. Though it was often referred to as a gasoline engine, in fact it was a steam engine. A gasoline burner was used to heat water, thus producing the steam that would propel the vehicle. In the summer of 1887, Olds was ready to road-test his invention. Though he had to give it a push to get it onto the street, it then ran a block before the engine showed signs of giving out, and Olds had to enlist the aid of friends to get his horseless carriage back to the shop.

Although other inventors had experimented with the idea of a horseless carriage and some had even tried to build one, Olds was the one who seized the initiative. During the next decade and a half, he worked tirelessly at perfecting the steam car, then applied what he had learned to the development of a gasoline-powered car, and finally used his practical experience to become a pioneer in the manufacture of automobiles. Between 1900 and 1903, there were more Oldsmobiles produced than any other car. Even after Oldsmobile became a part of General Motors in 1908, it continued to be not only a prestigious car but also one that often led the industry—for example, in making available such innovations as hydraulic brakes, an automatic transmission, front-wheel drive, and the air bag. The Oldsmobile was discontinued in 2004. However, the dedication to his craft that R. E. Olds had displayed when he introduced his horseless carriage 117 years before had become an Oldsmobile tradition, making the car bearing his name one of the most highly respected in the industry, and one whose demise is still mourned by automobile enthusiasts.

then using an assembly line to turn out the finished cars, Olds could switch his operation to the smaller plant in Lansing and continue to build cars while the Detroit facilities were being rebuilt. Despite the disaster, from 1900 to 1903 Oldsmobile produced more automobiles than any other American firm.

However, Olds found that he could no longer control the company he had founded. He was willing to let his backers handle financial matters and sales, but by 1904, when it became clear that Frederic Smith, the son of one of his original investors, intended to supervise production as well, Olds sold his stock, left the firm, and founded the R. E. Olds Company. When the Detroit Olds Motor Works threatened legal action because he had used "Olds" in the name of his new firm, he decided to use his initials instead. The first car built by the Reo Motor Car Company was markedly different from those Olds had previously designed. Instead of the curved dash, the Reo had a bonnet, or hood, which held batteries, the gas tank, and the radiator. It also had a running board and a steering wheel. Moreover, it was larger, heavier, and more powerful than the runabout, and it could carry five passengers. Although the company offered several other models, including its own runabout and an even larger touring car, the Reo was its best-selling vehicle. In 1905 and 1906, the new firm sold more cars than Olds Motor Works did, and in 1908 Smith's company was taken over by General Motors.

After 1915, however, Olds became increasingly less involved with automobiles. Instead, he devoted his time to other projects, manufacturing a lawn mower he had invented, for example, and trying his hand at investments and real estate. In 1916, he began building a large community on Tampa Bay in Florida, which he called Oldsmar, but it was not a success.

During the last four decades of his life, Olds enjoyed yachting both on the Great Lakes and in Florida and entertaining friends either at the family home in Lansing or at one of his summer places on the Great Lakes. Olds remained active until July 28, 1950, when he complained of feeling ill and was hospitalized. On August 26, he died of cancer. Metta Olds, who had been in ill health for some time, died of pneumonia on September 2, 1950.

IMPACT

Although he was actively involved in the development and manufacture of automobiles for only two decades, Olds is ranked as one of the most important figures in automotive history. Other inventors had experimented with horseless carriages, but they did not progress from prototype to plant as rapidly as Olds did. There are several reasons for his success. Olds's experience as a machinist enabled him to work his way through mechanical problems with relative ease. Moreover, he had a rare character trait: the gift of learning from his mistakes. He viewed each new vehicle he built as something that could be improved upon. Finally, he was true to his vision: the elimination of horse-drawn transport, which could only be accomplished if automobiles were inexpensive enough so that everyone could afford them. Olds's inventiveness is indicated by the fact that the thirty-four patents he obtained included such important automotive mechanisms as carburetors, clutches, engines, and tires.

Certainly, Olds's success inspired other talented young men to enter the automotive field. They were influenced by him in many ways, such as his commitment to the internal combustion engine, his body designs, and even the substitution of a steering wheel for a tiller. They utilized his inventions and imitated and refined his production methods; some of them, Henry Ford, for example, built their fortunes upon Olds's vision of an America where everyone could own a car.

Automobile production soon became one of America's largest industries, and Detroit, where Olds had built his large factory, became the center of production. Automobile ownership gave Americans more freedom than ever before, freedom to live where they liked and to travel whenever they pleased, and the development of the trucking industry gave them access to goods from all over the world. Thus, what began as a simple horseless carriage transformed American society.

—*Rosemary M. Canfield Reisman*

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; John Boyd Dunlop; Henry Ford; Charles Goodyear; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; André and Édouard Michelin; Nikolaus August Otto; Stanford Ovshinsky; Sylvester Roper; Ignaz Schwinn; Felix Wankel; Alexander Winton.

KEN OLSEN

American computer engineer

Olsen brought the minicomputer to the masses. Under his unique style of leadership, the Digital Equipment Corporation made small computers more efficient and affordable for businesses.

Born: February 20, 1926; Bridgeport, Connecticut
Also known as: Kenneth Harry Olsen (full name)
Primary fields: Computer science; electronics and electrical engineering
Primary invention: Minicomputer

EARLY LIFE

Kenneth Harry Olsen was born to Oswald and Svea (Nordling) Olsen as the second of four children. His father was a machine tool designer with several patents who kept a basement workshop full of tools. Olsen grew up in Stratford, Connecticut, under the strict religious fundamentalism of his parents, and he was almost always a well-behaved young man. After graduating from Stratford High School, Olsen served in the U.S. Navy from 1944 to 1946. There he received his first electronics training. In 1947, he entered the Massachusetts Institute of Technology (MIT) to study electrical engineering. He earned his B.S. in electrical engineering in only three years. With money from a graduation gift, Olsen followed a young lady from Finland who had decided not to finish college in the United States but to return home. Olsen caught up with Eeva-Liisa Aulikki Valve in Sweden, became engaged, courted her while the Cold War red tape generated by both the Finnish and the U.S. governments was settled, and on December 12, 1950, was married to her by her father. They returned to Massachusetts for Olsen to attend graduate school at MIT.

Olsen was able to work on the Whirlwind, a new type of digital computer being developed for the Navy to power a cockpit flight simulator. Whirlwind was different from other computers because it was interactive and worked in real time. A programmer could key in a program and get a seemingly instant response. Whirlwind was the basis for another computer called the Semi-Automatic Ground Environment (SAGE), which was to be used as an early warning system. Olsen directed a group to build a new computer to test the memory banks of the Whirlwind computer, and the task was completed in only nine months. That feat was so impressive that Olsen was rewarded with the task of going to Poughkeepsie, Massachusetts, to facilitate the interaction of MIT and International Business Machines (IBM) in building SAGE. This provided Olsen the opportunity to observe the production techniques of IBM. He was there for two and a half years and hated it. He felt that the company was inefficient and that he could beat IBM at its own game. In 1952, he was awarded his master's degree in electrical engineering.

LIFE'S WORK

In 1957, Olsen and Harlan Anderson, an MIT associate, went to the American Research and Development Company and received a grant of $70,000 to establish Digital Equipment Corporation (DEC). Olsen's younger brother, Stanley, joined the company on the first day. He would stay for more than twenty years. The first year, DEC built only printed-circuit logic modules for engineers to use in testing equipment. The next year, the company began to design and build the Programmed Data Processor-1 (PDP-1), an 18-bit computer that could perform many tasks such as track inventory or monitor scientific experiments, tasks that did not require a room-sized computer. It was successful, and in 1963 the PDP-4 was released, followed by the 12-bit PDP-5. A great breakthrough occurred with the PDP-8, released in 1965. Perhaps the first true minicomputer, it used tiny integrated circuits, which were faster and cheaper than transistors. The uses were uncountable. It could be programmed by a technician to control typesetting, a medical scanner, or even the scoreboard at Fenway Park in Boston. DEC's biggest machine, the mainframe PDP-10, was launched in 1967 to compete with IBM's mainframe computers. The PDP-11 was released in 1970 and became the most popular minicomputer in history. DEC also produced the DECnet software so that a small computer such as the PDP-11 could be attached to a large computer such as the PDP-10. This allowed the smaller computer to use the power of the large computer when the power was needed.

In 1974, DEC released the 32-bit computing architecture Virtual Address eXtension (VAX). VAX machines could be networked to one another so that each had the power of the others. The first superminicomputer, the VAX-11/780, was as powerful as a mainframe but at much less cost. The VAX package accounted for 40 percent of the world minicomputer market.

DEC failed to expand significantly into the microcomputer field in the early 1980's. Olsen did not see that people who had a computer at work might want one at home. Thus, as the microcomputers began to eat into the low end of the minicomputer market and as cheaper mainframes ate into the high-end market, DEC offered three different microcomputers. However, DEC had little retail expertise, and sales were slow. Soon, DEC's stock plunged. Olsen's reaction was to reorganize the company, discard the microcomputers, and push development of the VAX line. Olsen realized that when a person developed expertise on a microcomputer, he or she would eventually want to connect to a more powerful computer. Beginning with VAX clusters in 1983, DEC produced a line of VAX computers of all sizes that could be networked. The MicroVAX II workstation, with the power of the VAX-780 in a desktop-size machine, was hailed at the time as being as important as the IBM Personal Computer (PC) was when it first appeared in 1981. By 1986, the line included a networking system that would allow an IBM PC to retrieve data from any VAX computer. IBM had been unable to network even its own computers. The success of the new line caused many to call Olsen the most successful entrepreneur ever.

The development of more powerful microcomputers ate into DEC's market. The new competition and the recession in the early 1980's caused losses that even Olsen could not overcome before retiring (some say he was forced out) in 1993. He subsequently became chairman of Advanced Modular Systems, and in 1998 DEC was sold to Compaq. Olsen and Aulikki continued to live in a Boston suburb in the same modest home that they moved into when DEC was formed. They had four children, two girls and two boys. Olsen is a deacon in the Park Street Church. Aulikki died on March 2, 2009.

IMPACT

Before IBM's PC and other microcomputers brought computing to the masses, Olsen brought it to small businesses with the minicomputer. Powerful enough to accomplish innumerable tasks but small enough to be installed anywhere, the DEC minicomputers could be adapted to perform any task. Each company could program its particular software to suit that company's needs. DEC's minicomputers were also interactive. Results were quickly displayed on the cathode-ray tube and could be sent to a printer.

It is reasonable to say that the minicomputer generated the idea for the microcomputer. Once computers were developed for use at work, personal computers in the home soon followed. Also, Olsen and DEC helped establish the foundation for today's computer networking. Now computers are such that people around the world can interact with one another. It is now common for friends to talk long distance by computer or groups to have chat sessions online. Although Olsen did not develop this technology, his work made it possible.

—*C. Alton Hassell*

THE PDP-1 MINICOMPUTER

Released in 1960, the Programmed Data Processor-1 (PDP-1) was the first computer produced by Ken Olsen and the Digital Equipment Corporation (DEC). The PDP-1 was an interactive computer with a cathode-ray tube (CRT) similar to the kind used in televisions. A programmer could type in instructions and receive almost immediate results on the CRT or printer. There were several options for input/output: Besides the typewriter, which acted as a printer, programs could be written on punched tape. Computer cards could be translated to punched tape and inputted into the PDP-1. The CRT also had a light pen that could be used to input, change, or erase data.

The computer was based on microalloy-diffused transistors. It used an 18-bit word (eighteen 0's or 1's per word), and its standard main memory was 4 kilowords—about 9 kilobytes, or 9,000 bytes. The memory could be expanded to 64 kilowords (144 kilobytes). The memory's cycle time was 5 microseconds, which corresponds to a clock speed of 200 kilohertz. Most arithmetic instructions required 10 microseconds (about 100,000 operations per second). In contrast to the PDP-1, a modern computer may have more than 5 gigabytes (5 million kilobytes) of memory and do two billion operations per second.

The PDP-1 was slower and had much less memory than the mainframes, computers that filled entire rooms and required special air conditioning. In 1960, the PDP-1 was the size of a small refrigerator and did not require a sterile, air-conditioned room. It could be placed anywhere and cost $120,000, a fraction of the cost of a mainframe computer. Sales boomed after the International Telephone and Telegraph Company started purchasing the minicomputers to control its message-switching systems. The PDP-1 was powerful enough to do many jobs that did not need a mainframe. Both the Lawrence Livermore National Laboratory and the Atomic Energy of Canada used PDP-1s to control and monitor scientific experiments. Undergraduates at the Massachusetts Institute of Technology (MIT) developed a way to play music on the PDP-1 and produced programs that played the works of Mozart, Chopin, and Bach, among others. The first video game, *Spacewar!*, was developed for the PDP-1.

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Dobson, John M. *Bulls, Bears, Boom, and Bust: A Historical Encyclopedia of American Business Concepts*. Santa Barbara, Calif.: ABC-CLIO, 2007. Provides up-to-date information on Olsen and explains his leaving DEC and the sale of DEC to Compaq. Bibliography, index.

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See also: Nolan K. Bushnell; Seymour Cray; John Presper Eckert; Jay Wright Forrester; Bill Gates; William Redington Hewlett; Grace Murray Hopper; John William Mauchly.

J. ROBERT OPPENHEIMER

American scientist and physicist

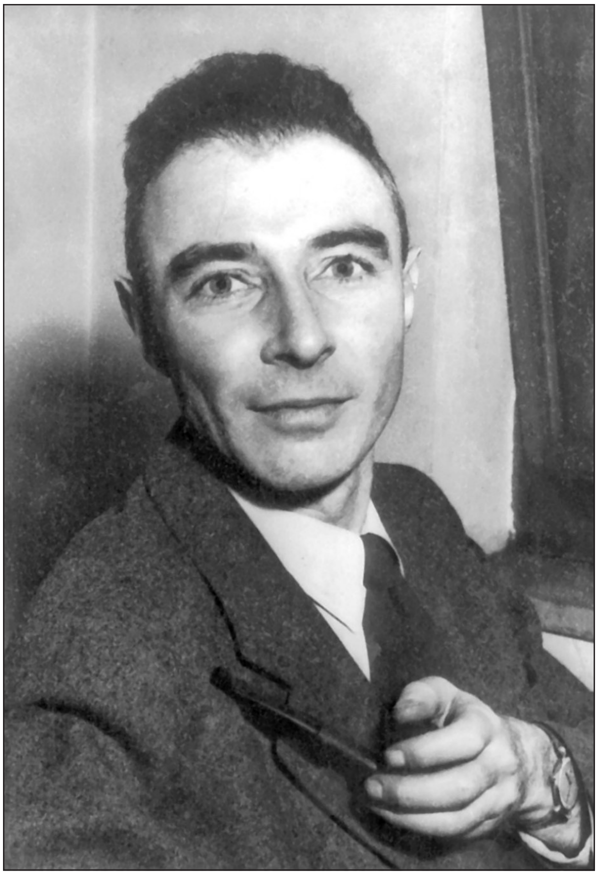
Oppenheimer led the Manhattan Project, which produced the first atomic bomb. He also did some of the earliest studies on subatomic particles, neutron stars, and black holes.

Born: April 22, 1904; New York, New York
Died: February 18, 1967; Princeton, New Jersey
Also known as: Julius Robert Oppenheimer (full name)
Primary fields: Military technology and weaponry; physics
Primary invention: Atomic bomb

EARLY LIFE

Julius Robert Oppenheimer (OP-ehn-hi-mur) was born in 1904 in New York City to Julius and Ella Friedman Oppenheimer, both of German-Jewish heritage. Julius was a partner in a successful fabrics company and Ella was a private art teacher, so Oppenheimer grew up in a privileged environment filled with intellectual discussion and the fine arts.

At the age of seven, Oppenheimer enrolled in the Ethical Culture School, a private institution with a progressive philosophy, where Oppenheimer showed an interest in science. In 1916, he wrote to several geologists about Central Park's rock formations. As a result, he was asked to join the New York Mineralogical Club and invited to speak. On the day of the lecture, the members were astonished to discover that Oppenheimer was only twelve years old.



J. Robert Oppenheimer. (NARA)

Upon graduation, Oppenheimer had to delay college because of illness. As part of his convalescence, he spent a summer journeying through New Mexico and fell in love with the state's rugged landscape, a fascination that would later influence the location of the atomic bomb enterprise in Los Alamos. In 1922, Oppenheimer entered Harvard University. Though he majored in chemistry, he discovered that physics was his real interest. Guided by Percy Williams Bridgman, Oppenheimer acquired a foundation in physics, while completing his chemistry degree in three years, summa cum laude. Despite showing little capacity for experimental work, Oppenheimer next went to Cambridge, England, to work with Joseph John Thomson on his electron detection experiments. Again, Oppenheimer demonstrated his incompetence in the laboratory.

However, at Cambridge, Oppenheimer read papers by Werner Heisenberg and met Robert Dirac and Niels Bohr—all of them physicists developing the new field of quantum mechanics. Discovering his calling, Oppenheimer left for the University of Göttingen, then the center of theoretical physics. By 1927, he had completed his Ph.D. and published, with Max Born, his first significant article, "On the Quantum Theory of Molecules." The paper explained the quantum behavior of molecules and would help establish high-energy physics in the 1990's.

LIFE'S WORK

After Göttingen, Oppenheimer accepted a dual professorship at the California Institute of Technology and at the University of California, Berkeley, where he and experimental physicist Ernest Orlando Lawrence, the inventor of the cyclotron, made a perfect team. Throughout the 1930's, Oppenheimer published groundbreaking papers on the positron, neutron stars, black holes, and the ability of deuterons to "tunnel" into atomic nuclei, the principle behind the tunneling microscope. It was also in the 1930's that Oppenheimer, concerned about Nazi Germany, became a member of the antifascist left. While he never joined the Communist Party, his brother Frank, his wife Kitty, and a number of his students did.

Just before the irruption of World War II, news emerged of a startling discovery—nuclear fission. Four German scientists—Otto Frisch, Otto Hahn, Lise Meitner, and Fritz Strassmann—found that neutrons can split uranium atoms, thereby releasing more neutrons and energy. There was also the possibility that with a critical

THE ATOMIC BOMB

As the scientific director of the Manhattan Project, J. Robert Oppenheimer led the difficult enterprise of using fission to create a nuclear weapon. The main problems at the Los Alamos National Laboratory were bomb weight, predetonation, and failure to achieve criticality. The Manhattan Project scientists and technicians, with Oppenheimer as their conductor, overcame these issues and invented two types of fission bombs between 1943 and 1945, though only one, the implosion bomb, would be stockpiled for strategic use.

The gun-type bomb, "Little Boy," used uranium 235 as its fissionable material, an isotope of uranium extracted from uranium hexafluoride. Little Boy was a steel cylinder 10.5 feet long and 29 inches in diameter. Its interior consisted of a cordite charge, a U-235 bullet, a set of U-235 target rings, and a steel tamper. When dropped, Little Boy's radar units signaled that the bomb had reached a predetermined height. This signal then set off the primers that lit the cordite. The ignited cordite slammed the bullet into the target rings. The subcritical masses then went critical, resulting in an atomic detonation. This was the bomb used on Hiroshima, Japan, on August 6, 1945. Despite its simplicity, there was only one Little Boy bomb assembled, because of limitations on U-235 production and the superiority of the implosion design in terms of yield.

The other Los Alamos bomb was the "Fat Man," an implosion weapon using plutonium. This design has remained the favored one for fission bombs. Standing at approximately 15 feet, Fat Man was essentially a sphere with fins built from multiple layers cased in steel. The outer layer consisted of wedge-shaped explosive lenses with two layers—an outer, fast-burning layer, and a slow-burning core. These explosive lenses wrapped around a uranium sphere, and within this sphere nestled two nickel-coated hemispheres of plutonium. A final innermost sphere of polonium completed the structure.

When Fat Man was dropped, radar devices signaled perimeter detonators to set off the wedge-shaped charges. The outer layers burned quickly, setting off convex shock waves. The slower burning cores reshaped the shock waves to concave, sending them toward the bomb's center. The uranium layer smoothed out the waves. These waves converged on the plutonium hemispheres, which would crush together, mixing the plutonium with the polonium. The polonium would send initial neutrons into the critical mass of plutonium, sparking a chain reaction and an atomic detonation.

Fat Man was dropped on Nagasaki, Japan, on August 9, 1945. Over the next decade, the Fat Man design improved, and implosion bombs became the triggers for the hydrogen bomb.

mass of uranium, one could create a chain reaction, resulting in a weapon of unimaginable power. This realization radically changed Oppenheimer's life, as well as world history.

Soon after World War II broke out on September 1, 1939, the United States started an atomic bomb project. Fearing that German physicists might be in the lead, Oppenheimer led a team exploring atomic bomb design. However, the American bomb effort was unfocused until September, 1942, when General Leslie Groves took charge and made Oppenheimer scientific director. Oppenheimer called for the project to be centered at an isolated laboratory, and by March, 1943, a former boys' school high in New Mexico's Jemez Mountains became Los Alamos National Laboratory.

Many challenges soon emerged. There were two potential bomb methods. The first, the gun-type bomb, sent a subcritical mass of fissionable material against a plug made of another subcritical mass. When the two subcritical masses met, they would go critical, producing a nuclear detonation. The other method, devised by Seth Neddermeyer, would send an explosive charge inward, crushing a core of fissionable material, thereby producing criticality. There were also two possible bomb materials. The first was uranium 235, an isotope painstakingly separated from uranium gas, an operation executed at Oak Ridge, Tennessee. The other substance was plutonium, an exotic element discovered by Glenn Seaborg. In Hanford, Washington, giant atomic reactors, based on Enrico Fermi's prototype, labored to produce the strange metal.

By mid-1944, it became clear that there would only be enough uranium 235 to produce one gun-type bomb by July, 1945. Thus, the gun-type bomb would not make a viable strategic weapon. On the other hand, Hanford was creating enough plutonium to create a workable atomic arsenal. However, plutonium emits abundant neutrons, and it would predetonate in a gun-style bomb. So, plutonium could only be used in an implosion bomb. For implosion to work, a shock wave must be precisely aimed at the bomb's core. Unfortunately, the implosion team, lead by George Kistiakowsky, had failed to produce this effect. For Oppenheimer, the director of the project, it was a major crisis.

Finally, in the early months of 1945, Kistiakowsky made a breakthrough by using high-explosive lenses to focus the shock wave. On July 16, 1945, the world's first atomic bomb, an implosion device, detonated at Trinity Site, a remote desert basin south of Albuquerque, New Mexico. The force of the blast was equivalent to nearly 19,000 tons of trinitrotoluene (TNT). On August 6, a B-29 bomber dropped the only gun-type uranium bomb on the Japanese city of Hiroshima. Three days later, a second implosion weapon fell on Nagasaki. Both cities were devastated. Death estimates, complicated by the effects of radiation, averaged 150,000 people in each city. On August 14, Japan surrendered.

While many Los Alamos scientists opposed using the bomb on a city, arguing instead for a demonstration followed by a call to surrender, Oppenheimer supported the military use of an atomic weapon, believing that a failed demonstration would only embolden the Japanese. Yet, after the war, Oppenheimer argued vociferously for tight restraints on atomic bomb production, for international control of atomic weaponry, and against hydrogen bomb development. He did not succeed in these goals, and the nuclear proliferation he warned against became a stark reality. When the Soviet Union exploded its first atomic bomb on August 29, 1949, the arms race was in full stride.

In the late 1940's, Oppenheimer became the director of the Institute for Advanced Study in Princeton, New Jersey, and served on committees for the Atomic Energy Commission (AEC). Despite his key role in atomic bomb research, the growing anticommunist atmosphere of the 1950's ultimately engulfed Oppenheimer. In June of 1954, the AEC denied Oppenheimer his security clearance. He was barred from all official connections with the United States government, including the lab at Los Alamos. The AEC cited as reasons Oppenheimer's left-wing past and his opposition to thermonuclear weapons.

After his security hearing, Oppenheimer was bitter and subdued. While he remained the head of the Institute for Advanced Study, he did little research, and he was critical of the burgeoning development of nuclear arsenals. He died of throat cancer on February 18, 1967.

IMPACT

Oppenheimer's legacy is as multifaceted as the man. He was a complex person, and his contribution of the atomic bomb problematic. He is often viewed as a Faustian figure—a compassionate person filled with scientific zeal who traded his ideals for the destructive illusion of power. However, he is also seen as the brilliant physicist who helped save the world from fascism and attempted to restrain his dangerous invention. Also, as the leader of the world's first large-scale scientific project, he helped formulate the groundwork for later major endeavors like the space program.

The atomic bomb became the major nations' strategic weapon of choice. Oppenheimer watched with trepidation as the Russians detonated their first nuclear weapon, and then the United States and Russia, within nine months of each other, set off the first hydrogen bombs in 1952 and 1953. Since then, the nuclear powers have spent trillions of dollars on tens of thousands of atomic weapons. The delivery systems for nuclear weaponry include bomber jets, intercontinental missiles, and nuclear submarines. In addition to full-out nuclear Armageddon, there have been fears of nuclear terrorism. All of this Oppenheimer warned against and tried to prevent through his pleas for international control.

However, as Oppenheimer had hoped, nuclear weapons, due to their horrible nature, have prevented new world wars. Also, there are peaceful uses of atomic energy—from power generation to medicine—all of which emerge from Trinity's fiery cauldron. Finally, Oppenheimer's work in quantum physics helped produce an amazing outpouring of inventions, for quantum principles are the basis for computer technology, genetic engineering, laser technology, and many other aspects of the modern high-technology era.

—*John Nizalowski*

Further Reading

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Thorpe, Charles. *Oppenheimer: The Tragic Intellect*. Chicago: University of Chicago Press, 2006. Using the concepts of Max Weber and other major sociologists, Thorpe examines Oppenheimer's life in the context of society and culture, and how he is emblematic of American society's concept of the scientist. Illustrations, bibliography, index.

See also: Luis W. Álvarez; Albert Einstein; Enrico Fermi; Donald A. Glaser; Ernest Orlando Lawrence; Willard F. Libby; M. Stanley Livingston; Edward Teller.

Elisha Graves Otis

American mechanical engineer

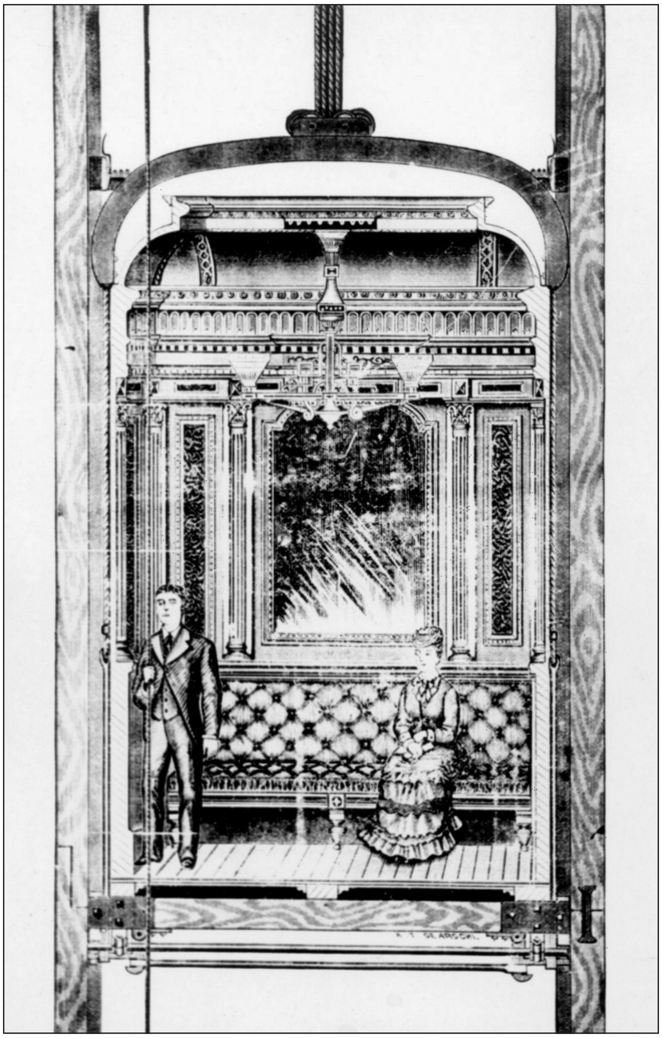
In 1852, Otis invented the first elevator equipped with the sort of safety brake that, without human intervention, would immediately keep it from falling were its cable to break. In 1854, he founded a company to manufacture, install, and maintain elevators with such safety devices.

Born: August 3, 1811; Halifax, Vermont
Died: April 8, 1861; Yonkers, New York
Primary fields: Manufacturing; mechanical engineering
Primary invention: Safety elevator

Early Life

Elisha Graves Otis was the son of Stephen and Phoebe Otis, farmers who lived in Halifax, Vermont, when Vermont was so sparsely populated that all its residents could have fit on a modern city block. Like many farm children, Elisha resisted following in his parents' footsteps. The repetitive seasons and the monotony of the daily chores accompanying this repetitiveness bored the young Otis, who had a fertile mind and a strong imagination. He was among the thousands of young people of his era who forsook their rural birthplaces for urban centers.

Anything mechanical interested the young Elisha.



An Otis hotel elevator, 1881. Wood engraving. (The Granger Collection, New York)

When the farm machinery his parents used broke down or worked inefficiently, Elisha, even before he reached his teens, devised ways of repairing and improving such machinery. Among his favorite haunts was the local blacksmith's shop, where he tinkered with farm implements brought in for repair or upgrading. By age nineteen, Elisha knew for sure that his future was not in farming but in some still undefined occupation where he could sharpen his mechanical skills. Finally, with his father's consent, he left Halifax for Troy, New York, where his brother lived and where he had been offered work.

Troy was a thriving community less than one hundred miles from Halifax and slightly north of Albany, New York. It was located on the Hudson River, a waterway that provided power for the many mills along its course and that also provided a means of transporting materials south to New York City and other ports, using both the river and the Erie Canal for transport. Elisha was intrigued by Troy's small factories and by the mechanical and technological advances that were to usher in America's industrial age.

At that time, most manufacturing operations were small, many of them established by farmers who needed something to keep them busy and to provide extra income during the slack winter months. After he left Halifax, Elisha drifted from job to job in small factories or in other enterprises. He spent five years working in construction for his brother Chandler in Troy. After that, he spent three years hauling freight between Troy and Brattleboro, Vermont, in his own wagon.

Otis began to have family responsibilities. In 1832, he married Susan Houghton. The pair became the parents of four children. When Susan died in 1842, the care of these children fell to Otis. In 1845, he was remarried, this time to Elizabeth Boyd.

In 1838, he established a grist mill in Brattleboro, but it failed within its first year, whereupon Otis converted it into a sawmill and a shop that built wagons and carriages. By 1845, Otis had moved to Albany, where he became a mechanic in a company that made bedsteads, the frames on which a bed's springs and mattress are placed. During this period, he invented an automatic bed turner. In 1848, he opened his own business, Hudson Manufactory, to produce and market his invention.

LIFE'S WORK

For his first forty years, Otis seemed to have little direction. He drifted from job to job. He was honest, dependable, and capable of supporting his wife and four children, but he lacked the sort of personal drive and ambition that might have made him a captain of industry.

In 1851, when his Hudson Manufactory failed, he seriously considered joining the legions of adventurers flocking to California during the gold rush that began in 1849. Had he joined this throng, he would likely have arrived too late to be rewarded significantly for taking the risk involved in leaving the eastern United States to relocate three thousand miles across the continent to California's gold fields. Instead, Otis followed his friend Josiah

Maize to Bergen, New Jersey, where Maize opened a factory that made bed frames. In 1852, when Maize moved this factory to Yonkers, New York, Otis again toyed with the prospect of going to California but decided instead to continue his association with Maize, who valued his efficiency and dependability.

The move to Yonkers marked a turning point for Otis. Maize put him in charge of moving his factory from Bergen, a move that required the use of hoists to transport the factory's heavy equipment without damaging it. This requirement was not easy to achieve because the hoists involved had to lift very heavy equipment. These hoists were little more than platforms lifted by thick rope cables. Most hoists then in use fell and crashed to the ground below them when the cable supporting them frayed and broke, which often happened. Such crashes destroyed expensive equipment and frequently resulted in injury or death for those operating them. Otis, a skilled inventor, set about constructing a safe hoist to move Maize's equipment.

Before long, he had constructed a hoist that would not fall precipitously if the cable supporting it broke. Soon, news of Otis's invention spread, and requests for his "safety hoist," as it was initially called, trickled in. Otis began to manufacture his invention, working on it part-time in Maize's facility in Yonkers. In 1854, after Maize went out of business, Otis stayed on and gave his full attention to manufacturing the safety hoists for which there was a growing demand.

As his business grew, Otis became a bit of a showman. He regaled audiences at the American Institute Fair in New York City's Crystal Palace by standing on one of his safety hoists and having it elevated to more than thirty feet. Then he had an employee slash the rope cable that supported the hoist. Audiences gasped because, had the hoist plunged to earth, as many were sure it might, the fall would have killed or seriously injured Otis. Rather than plunging to his death, however, Otis felt a small jolt as the platform's fall was brought to an immediate halt as his invention engaged automatically. These demonstrations, seen by hundreds of people, brought a flood of orders for Otis's invention.

At this point, safety hoists were used exclusively for moving freight. In 1857, however, Otis built an enclosed platform, creating an elevator intended to transport people from floor to floor within buildings, few of which at this time rose to more than five stories. This first passenger elevator, installed in a department store in New York City, rose along toothed guide rails and had a system for stopping the elevator the moment its cable became slack.

By 1861, the year Otis succumbed to diphtheria during an epidemic, he had produced a steam-driven elevator that rose at the rate of five stories per minute, a model that became the standard when Otis's sons, Charles and Norton, took over his corporation following his death.

THE SAFETY ELEVATOR

Hoists have been used in construction since ancient times. The builders of the Egyptian pyramids and the Roman aqueducts had to move heavy construction materials and equipment to considerable heights and used hoists to accomplish this feat. The principle of using hoists was somewhat refined through the years, but their basic design did not change dramatically until the middle of the nineteenth century. In 1857, Elisha Graves Otis installed the first passenger elevator in a New York City department store. Until then, elevators, called hoists, were used primarily to lift heavy equipment above ground level in buildings that ranged in height from two to five stories.

The hoists in common use in the first half of the nineteenth century were platforms set between parallel frames, usually made of wood or metal, and supported by thick rope cables, usually made of hemp. The hoists' guide rails were ratcheted, which limited them to moving in just one direction. When the hoist carried heavy loads, the supporting cables often frayed and eventually broke, dropping their cargoes to the ground below. Current safety devices used in modern elevators are descendants of early devices invented by Otis, who understood fully the dangers that most of the early hoists presented. Otis's safety hoist attracted considerable attention, and demands for it grew quickly.

In Otis's safety hoist, a cable that controls a governor at the top of the structure was attached to the side of the elevator's compartment. If the governor turned faster than it should, it triggered a safety switch automatically, an action that engaged a brake on the drive pulley. The cable of Otis's safety hoist was attached to a spring atop the frame of the hoist. Tension on the rope cable bent the spring and drew back the cams on each side of the frame, which prevented them from engaging the hoists' guide rails. If the cable broke, the spring straightened, which forced the guide rail's cams to engage, thereby keeping the hoist from falling. This action should stop the elevator safely, but the fail-safe system that is used in most modern elevators makes provision for possible brake failure, causing the governor to grab the brake cable, whose safety clamps then wedge against the guide rails on both sides of the frame.

Although the name Otis is generally associated with elevators and gave rise to the Otis Elevator Company that has operated through three centuries, Elisha Otis contributed other inventions to a society rapidly becoming industrial and technological. Among the inventions for which he received patents were a steam plow, an advanced baking oven, and a brake for railcars.

IMPACT

Before Otis's invention of the modern elevator, cities in the United States were horizontal. It was impractical to erect buildings of more than five stories because of the difficulty of moving people and equipment to greater heights. Otis's invention has had a profound effect on modern architecture because it made possible the construction of the skyscrapers that create the dramatic skylines of most of the world's modern cities.

Otis, almost single-handedly, changed skyscapes throughout the world from horizontal to vertical as buildings soared to new heights, limited primarily by the ability of very lofty buildings to accommodate the banks of elevators necessary to make them usable and practical.

As modern elevators became faster, the buildings that housed them soared to new heights. In some of the major cities of the world, it is possible to dine over one hundred stories above the street. In some cases, as in Chicago's John Hancock Tower, which has 102 stories, people eating in the restaurant on the top floor can look down upon small airplanes as they fly toward the landing strip at Meigs Field. It is doubtful that Otis himself could have envisioned such a scenario.

—*R. Baird Shuman*

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See also: Peter Cooper; Jesse W. Reno; Frank J. Sprague.

NIKOLAUS AUGUST OTTO

German mechanical engineer

The Otto-Langen atmospheric engine improved Étienne Lenoir's internal combustion engine. Most important, Otto's invention of the four-stroke engine was decisive for the development of the modern internal combustion engine.

Born: June 10, 1832; Holzhausen, Nassau (now in Germany)
Died: January 26, 1891; Cologne, Germany
Primary field: Mechanical engineering
Primary invention: Four-stroke internal combustion engine

EARLY LIFE

Nikolaus August Otto was born on June 10, 1832, in Holzhausen, Nassau. Located on the banks of the Rhine, the village was part of Prussia's Rhineland provinces, which became part of the newly created Germany in 1871. All Otto's ancestors were farmers, bakers, and innkeepers who came from this Taunus and Westerwald region. His father, Philipp Wilhelm, was a farmer and innkeeper who also held a position as a postman in Holzhausen. None of Otto's ancestors exhibited any technical or engineering skills.

Otto was the sixth and youngest child in his family.

His father died shortly after his birth, leaving the mother with the responsibility of raising the family. After elementary school, Otto attended secondary school (*Realschule*) in Langenschwalbach between 1846 and 1848. Although his mother wanted Otto to obtain a technical education, because of her financial problems the boy left school and in 1848 started an apprenticeship as a salesman in Nastätten. After completing his training, he spent one year in a general merchandise store in the region. With the help of his brother Wilhelm, he obtained a similar job in Cologne. Between 1851 and 1862, he was a traveling salesman for such items as rice, sugar, coffee, tea, and straw bundles. His customers were primarily small shop and store owners.

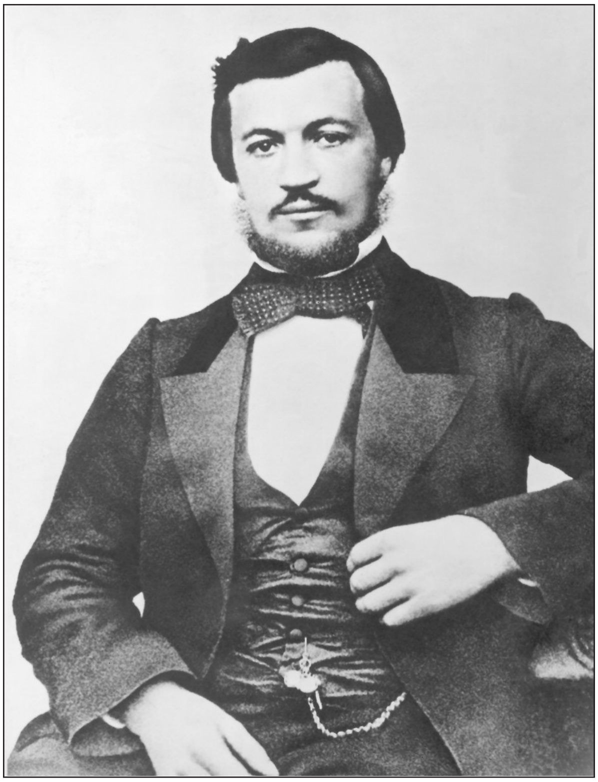
Because Otto left no exact descriptions of his work habits, it is not known when or why he first became interested in motors, particularly since he had no technical education. However, like many other inventors in the mid-nineteenth century who also lacked engineering education, Otto learned by tinkering with machines. According to his unpublished recollections of 1889, in 1860 he read about the construction of a gas engine by Étienne Lenoir, and he studied it carefully. At this time, he lived with Wilhelm, who participated in and financed his brother's early experiments with motors.

LIFE'S WORK

Otto wanted to improve the performance and construction of the Lenoir engine. Although that noncompression, internal combustion gas engine was a potential alternative to steam engines, it suffered from serious shortcomings. It consumed an enormous amount of expensive gas and required huge quantities of cooling water. In addition, the bearings had to be constantly lubricated. Otto, who was familiar with the energy needs of small shops and businesses, decided to focus on improving the Lenoir engine and commissioned mechanic Michael Zons to build one in 1861. In 1863, Otto had an atmospheric engine constructed. It used a free piston and one-third less gas than the Lenoir engine; however, it was not commercially viable. By the end of that year, Otto was short of funds, and the state of Prussia had rejected two of his patent applications.

In 1864, Otto's career as an inventor was rescued when he met Eugen Langen, an engineer and prosperous businessman. For the next quarter century, Langen provided the financial support essential for Otto's work, and he also contributed to the improvement of Otto's 1863 engine by designing a workable clutch. The two men formed a company, N. A. Otto and Cie, and their combined efforts produced a successful atmospheric internal combustion engine, the Otto-Langen engine. A mixture of gas and air was ignited to drive a piston up the cylinder, and the piston's weight plus the atmospheric pressure brought the piston back down. In 1866, the firm was granted a patent for the engine, and in 1867 the engine was awarded a gold metal at the Paris Exposition for its fuel economy.

In 1872, the firm was reorganized as the Gasmotorenfabrik Deutz corporation, and it hired Gottlieb Daimler as production manager and Wilhelm Maybach as machine designer. For a time, the Otto-Langen engine was a commercial success. However, it could not meet the demand for more power since it could produce only about three horsepower. Since Otto and Daimler clashed constantly—and spurred on by the dire warnings of Langen's close friend, professor Franz Reuleaux, of competition from more powerful engines—the firm established two company laboratories, one headed by Otto and the other by Daimler. In early 1876, Otto, with the help of the machinist Franz Ring, solved the horsepower problem and returned to one of his previous ideas of



Nikolaus August Otto, inventor of the four-stroke-cycle internal combustion engine. (Getty Images)

THE SILENT OTTO

Nikolaus August Otto's most important invention, the four-stroke-cycle internal combustion engine, was built in 1876 and marketed by the Gasmotorenfabrik Deutz firm as "Otto's new motor," although it soon became known as the "Silent Otto" engine because it was less noisy than the Otto-Langen atmospheric engine. The Silent Otto was patented the following year, based in part on Otto's controversial argument that the special stratification of the gas/air compression he had adapted was the most revolutionary feature of this engine. In fact, it was the four-stroke cycle, allowing for the compression of the gas/air mixture within the working cylinder, that made this engine so innovative. Otto's engine was a horizontal, stationary machine, designed primarily for shops, printing presses, power stations, and other similar facilities. Unlike the Lenoir internal combustion engine, the compression occurred within the working cylinder. Also, the Silent Otto could produce more horsepower than the Otto-Langen atmospheric engine. The Silent Otto established the internal gas combustion engine as the most important new power source for industry and consumers, rivaled only by the massive expansion of the use of electrical power.

Otto's new engine established the basic principles that defined all future four-stroke-cycle internal combustion engines, regardless of size or horsepower. During the first stroke, the piston moves downward toward the crankshaft. Because of the resulting drop in pressure, a fuel and air mixture enters through the intake valve. When the cylinder obtains its maximum volume, the valve closes and the piston returns toward the top of the cylinder, compressing the gas/air mixture. This compressed mixture is then ignited by a spark, and the resulting force creates the third stroke, which forces the piston downward in the direction of the crankshaft and delivers the direct work force. When the piston reaches the bottom, the exhaust valve opens, allowing the gas to exit the cylinder. After the piston returns to the top of the cylinder, the four-stroke process is repeated.

The first Otto engine delivered only three horsepower, but by the time of Otto's death in 1891, his engines were producing as much as one hundred horsepower. Because the first engine weighed 1,450 pounds per horsepower and was dependent on urban gas supply, it was limited to urban stationary use. Otto's engine, however, evolved both in terms of power and size. By increasing the compression ratio, the engine became more powerful and the size and weight of the engine was reduced significantly, allowing it to become mobile. In 1885, Otto's old colleagues Wilhelm Maybach and Gottlieb Daimler produced a petrol gas engine weighing only 88 pounds and producing one-half horsepower. This was only the beginning of a series of developments in the emerging automobile industry. After Otto lost his German patent in 1886, his four-stroke engine became available to all entrepreneurs, helping to launch the automobile revolution in the 1890's.

compressing the gas and air in the cylinder. Otto, who invented this revolutionary four-stroke cycle (four piston strokes for each power stroke), thought that his major contribution was that he used a stratified layer of gas/air mixture that cushioned the shock to the piston.

"Otto's new motor"—nicknamed "Silent Otto" because it operated with much less noise than the atmospheric engine—was first patented in Alsace-Lorraine on June 5, 1876, and then recognized by the newly created German patent system in 1877. Unfortunately for Otto, the patent was challenged in court. Frenchman Alphonse-Eugène Beau de Rochas had patented the four-stroke engine in 1862, but he never built this engine. Even though there is no evidence that Otto knew of Rochas's ideas, in 1886 Otto's patent was rescinded in Germany. It remained valid in Great Britain and Austria. Despite this, he continued his research, receiving a patent in 1887 for his work on an ignition system for stationary petrol motors. Still, the trials took a heavy toll on Otto's health, and he died of heart failure on January 26, 1891. His only son, Gustav, continued his father's interests by becoming an engineer and founding an aircraft company in 1901.

IMPACT

Otto's pioneering work with engines contributed significantly to the economic and technological modernization of the world. Otto and Langen's firm Gasmotorenfabrik Deutz was the world's first factory devoted to the manufacture of internal combustion engines. It still operates in Germany, producing gas and diesel engines for the world market. Moreover, the Otto-Langen engine was the first internal combustion engine that was a commercial success. The firm and its licensed associates eventually sold five thousand Otto-Langen engines, totaling six thousand horsepower.

Even more important for the world economy was the creation in 1876 of Otto's four-stroke engine, the forerunner of most modern automobile engines. Between 1877 and 1889, the Deutz firm produced 8,308 four-stroke engines, and a firm in Manchester, England, manufactured thousands more. In 1878, at the Paris Exhibition, the Otto engine was judged the best of seventy-five models. Reuleaux called it the greatest discovery of a power machine since the contribution by James Watt. By 1889, only four out of fifty-five engine models exhibited at the Paris Exposition were noncompression gas engines. Also, the introduction of the Otto engine in Philadelphia in 1876 stimulated massive interest in this new source of power in the United States. Fifteen years later, 18,500 Otto-cycle engines were operating in the United States.

After Otto's German patent was revoked in 1886, there was an explosion in car engineering and production that relied on the four-stroke internal combustion engine. In the July, 1894, road race from Paris to Rouen (seventy-eight miles), only seven of the twenty-one cars participating were steamers, and only one of these finished in time. By 1907, the world's largest car producers, the United States and France, had manufactured nearly seventy thousand cars.

—*Johnpeter Horst Grill*

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; Henry Ford; Étienne Lenoir; Sylvester Roper; Felix Wankel; James Watt.

STANFORD OVSHINSKY

American machinist and scientist

Ovshinsky pioneered the field of disordered materials research known as ovonics and became a leading developer of hydrogen as an alternate fuel source. His work led to key developments in energy and information technology.

Born: November 24, 1922; Akron, Ohio
Also known as: Stanford Robert Ovshinsky (full name)
Primary fields: Automotive technology; mechanical engineering; physics
Primary invention: Ovonic switch

EARLY LIFE

Stanford Robert Ovshinsky (ov-SHIHN-skee) was born on November 24, 1922, in Akron, Ohio. He was the son of Lithuanian scrap dealer, Benjamin Ovshinsky, and his wife, Bertha Munitz. His parents instilled in him a passion for social causes. Although Ovshinsky was an avid reader with an especially keen interest in science, he never attended college. Instead, he acquired his scientific knowledge by haunting public libraries during his early life. After graduating from high school, he attended trade school to train as a machinist. He married his first wife, Norma Rifkin, and lived for a time in Arizona, where he worked in the tool room of the Goodyear plant in Litchfield. He then opened his own machine shop called the Stanford Roberts Company. In the early 1940's, Ovshinsky invented a popular automated high-speed center-driven lathe known as the Benjamin Center Drive. He later sold his company to the New Britain Machine Company.

In 1951, Ovshinsky moved to Detroit, Michigan, and accepted the position of research director at Hupp Motorcar Company, an automotive parts manufacturer. At Hupp, he was involved in the development of electric power steering. He also developed an interest in human intelligence and its uses in developing machine intelligence as well as in neurophysiology. He formed a new company, named General Automation, in conjunction with his brother Herb. He also received a 1955 invitation from Wayne State University to participate in research on the mammalian cerebellum. His experiments with switches reminded him of research he had done on how neurons functioned within the human brain. He realized that the brain uses and stores energy without the benefit of an ordered structure, and he believed that science could engineer energy information systems that would work the same way. This work began his lifelong interest in what became known as amorphous, or disordered, materials, materials in which atoms are not linked together in a precise order.

LIFE'S WORK

Ovshinsky first had to prove to an often skeptical scientific community that amorphous materials existed. He next learned how to produce thin layers of the materials at a relatively affordable cost. He started with elements such as sulfur, selenium, and tellurium, but later moved on to chalcogenides. At the same time, he continued his studies into the human brain and its relation to his other work. He designed a nerve cell model, which his brother Herb built, to further his understanding. Ovshinsky's research resulted in the discovery of the "Ovshinsky effect," by which thin, glassy films of amorphous materials become superconductors when low voltage is applied to them. He utilized this effect to produce electronic and optical switches that worked at high rates of speed, beginning with his first ovonic switch in 1957. In 1960, Ovshinsky cofounded Energy Conversion Devices (ECD) with his second wife, Iris Dibner. She had a B.A. in zoology, an M.S. in biology, and a Ph.D. in biochemistry and was his lifelong business partner until her death in 2006.

Ovshinsky and his company were interested in using their ovonics technology to further the search for alternative energy sources to fossil fuels. Ovshinsky felt that hydrogen could both produce and store energy through what he termed the "hydrogen loop," whereby water in a fuel cell is converted to hydrogen through solar-powered electrolysis and is then converted back to water, generating electricity in the process. He also achieved fame for his invention of the nickel-metal hydride (NiMH) battery used to power portable electronic devices and hybrid electric cars, including the 1999 model of General Motors' EV1. Ovshinsky utilized his methods to produce thin-film solar cells. He also designed a solar factory in Michigan featuring a shop floor with a flexible, durable, self-adhesive strip of power-generating solar material. In the 1980's, he developed solar roofing materials.

In addition to energy storage and generation, Ovshinsky's ovonics works had applications in the information technology (IT) field. Ovshinsky saw the two fields as compatible, calling information "encoded energy." His patents have been used in computer processes and

Stanford Ovshinsky, middle, at his laboratory, where experiments in ovonics are conducted. (Time & Life Pictures/Getty Images)

nonvolatile memory, rewriteable optical data storage discs, and silverless photography. His optical storage discs allow new data to be written over undeleted old data. In electronics, his work was utilized in the development of flat-panel liquid crystal display (LCD) and high-definition (HD) televisions. Japanese electronics companies licensed his technology in the 1980's to produce digital video discs (DVDs).

Ovshinsky received adjunct professorships in engineering science and physics at Wayne State University and the University of Cincinnati, respectively. He has received a number of awards and professional honors over his lifetime. He is a fellow of both the American Physical Society and the American Association for the Advancement of Science. He received the 1966 Diesel Gold Medal from the German Association of Inventors, the 1988 Coors American Ingenuity Award, the 1991 Toyota Prize for his invention of the hybrid ovonic nickel-metal hydride battery, the 2005 Innovation Award for Energy and the Environment from *The Economist* magazine, several awards for his work in solar energy, and the International Association for Hydrogen Energy Sir William Grove Award.

In 1988, the Public Broadcasting Service (PBS) show *Nova* profiled Ovshinsky in a show titled "Japan's American Genius." His numerous publications have also received recognition, including the 1992 International Symposium for Electric Vehicles award for best article. After the 2006 death of his wife and business partner Iris, Ovshinsky retired from ECD and launched Ovshinsky Innovation, LLC, with his soon-to-be third wife, Rosa Young. He continued to work on photovoltaic energy projects for use in buildings as well as his idea for a cognitive computer with a memory similar to that of the human mind. He has received hundreds of patents over the course of his career.

IMPACT

Although the scientific community greeted many of the self-educated Ovshinsky's ideas with skepticism, he persevered in demonstrating that they had key research and commercial applications and that he could take them from

THE OVONIC SWITCH

Stanford Ovshinsky's research into amorphous, or disordered, materials and phase-change technology led to his development of the first ovonic switch in 1957. ("Ovonic" was coined from the first two letters of his last name and "electronic.") Most scientists at the time did not see the value of amorphous materials, instead working with ordered crystalline solids. Ovshinsky, however, discovered that when amorphous materials such as chalcogenide alloys were charged to a certain voltage with electricity or laser beams, they changed phase, assuming an ordered structure. The materials could then be switched back and forth from the amorphous structural phase, known as "zero" or "off," and the ordered structural phase, known as "one" or "on." The discovery was a direct result of his quest to apply his earlier research on the functioning of mammalian brain cells, in particular neurons that worked like "on/off" switches, into the design of an energy-information system.

Ovshinsky's discovery of the ovonic switch revolutionized semiconductor and phase-change technology. The fast speed at which the ovonic switch could change phases gave it a variety of uses in the fields of energy and information technology (IT). Also valuable was the fact that the ovonic materials on which the switch is based can be custom-made and produced in larger quantities than ordered crystalline materials. Ovshinsky's proof of the existence and value of amorphous materials along with his discovery of the ovonic switch allowed him to overcome the academic skepticism that greeted his early ideas and allowed his company to attract corporate sponsorships and government research grants to further his work.

Ovshinsky developed a number of other ovonic switches based on the first 1957 switch, including the ovonic phase-change memory switch and the ovonic threshold switch. In 1968, Ovshinsky announced that his company Energy Conversion Devices (ECD) had made an ovonic switch out of amorphous silicon. Many of ECD's other subsequent products and innovations were also based on the technology behind amorphous materials and their use in the ovonic switch. In the field of energy, these included his work on hydrogen as an alternative energy source, his development of thin and flexible solar cells, his work on the nickel-metal hydride (NiMH) battery, and the development of new fuel cells. In the field of IT, these included computer processors and memory, flat-screen and high-definition technology, and optical recording technology such as rewriteable CDs and DVDs.

visions to inventions. The new physics field of amorphous materials that he pioneered bears his name, ovonics, a term in common usage. A variety of past and present inventions rely on ovonics technology and his patents, and scientists are studying ovonics materials in a variety of fields, including their use as superconducting materials that allow researchers to work at much higher temperatures than that of conventional superconducting materials. Due to the depth and breadth of his ideas and inventions, he has repeatedly drawn comparisons to renowned scientist Albert Einstein and renowned inventor Thomas Alva Edison. Through his company, he has worked with a number of prominent scientists, including Hellmut Fritzsche, Morrel Cohen, David Adler, Sir Neville Mott, John Bardeen, Arthur Bienenstock, Kenichi Fukui, William Lipscomb, and Linus Pauling.

Ovshinsky's work on the "hydrogen economy" as a potential source for creating and storing energy put him in the forefront of the movement to develop cleaner, more renewable energy sources than fossil fuels and to lessen U.S. dependence on foreign oil imported from regions such as the Middle East. For example, hydrogen fuel cells that rely on his hydrogen-loop technology are a potential replacement for the standard internal combustion engine. Ovshinsky emphasizes the social as well as commercial benefits of clean energy. His work has helped the effort to make the future of electric cars, solar panels, and other green technology more realistic and affordable on a mass scale. For example, he proved that electric cars could travel adequate distances without recharging while driving at normal highway speeds. His company made photovoltaic cells that were used on the Mir space station to generate electricity from sunlight.

Although Ovshinsky's company never achieved steady profitability, his technological developments are finding their way into the commercial market on a greater scale through his company's partnerships with a number of major corporations, including Intel, Samsung, General Electric, and Chevron. For example, ECD partnered with Sharp and Standard Oil to mass-produce solar energy cells made of ovonic materials. Originally used to power calculators, they may someday be cost-effective enough to power homes and businesses.

—Marcella Bush Trevino

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See also: John Bardeen; J. Georg Bednorz; Mark Dean; James Fergason; Sumio Iijima; Paul B. MacCready; Karl Alexander Müller; Robert Norton Noyce; Claude Elwood Shannon; Robert Stirling.

LARRY PAGE

American computer scientist

Page's development of the PageRank algorithm made it possible to assess more accurately the information content and usefulness of a given page on the World Wide Web and foiled several common methods for tricking search engines into ranking pages more highly than they deserved.

Born: March 26, 1973; East Lansing, Michigan
Also known as: Lawrence Edward Page (full name)
Primary fields: Computer science; mathematics
Primary invention: PageRank algorithm

EARLY LIFE

Lawrence Edward Page may well have been destined from birth to become a computer specialist. His father, Carl Victor Page, was one of the first people to receive a computer science degree from the University of Michigan. His mother, Gloria Page, was a database consultant who worked on huge mainframe computers. Larry spent most of his childhood in East Lansing, Michigan, where his father was a professor of computer science at Michigan State University.

Google cofounder Larry Page. (Getty Images)

When Larry was eight, his parents divorced. He and his older brother Carl, Jr., lived with their father, who developed a long-term relationship with another computer science professor, Joyce Wildenthal. However, Larry was also close to his mother, and he came to see both women as mother figures. Interestingly enough, the two women were close friends rather than rivals, and they collaborated to make sure that the boys could have as normal and healthy a childhood as possible.

Although Larry developed his fascination with science and technology early in his life, his inquisitive mind ranged far in the social sciences and politics as well. His family had a history of activism for liberal causes, and Larry would internalize that commitment to socially positive activity.

Larry decided to go to Stanford University for his degree in computer science. During his second year, his father took ill and died. The sense of loss was nearly overwhelming, but Larry determined to stay in school and earn his degree. He subsequently went for a master's degree and started on a doctoral program in computer science.

LIFE'S WORK

While working on his doctorate, Page became interested in the World Wide Web, in particular search engines, programs that enable users to find particular information in which they are interested. Early search engines indexed the content of Web pages but had little in the way of determining the value of the information. As a result, techniques such as "keyword stuffing" were frequently used by shady Web designers to inflate the ranking of their pages.

At first, Page was attracted to the problem as an intellectual puzzle, a suitable subject for his doctoral dissertation. Computers dealt best with facts. Making value judgements about information was a matter generally left to human minds. However, the World Wide Web was simply too large to hire enough people to evaluate all the pages to be indexed. Therefore, one had to find some easily recognizable characteristic that would effectively indicate the value of a Web page. Page found his answer in the hypertextual nature of the Web. He realized that each hyperlink to a Web page was in effect a person's judgement that the content to be found there was indeed worthwhile. One needed only count the votes and weight them appropriately to come up with a value for the actual usefulness of the Web page. This was the principle behind the link analysis PageRank algorithm, named for its inventor and its purpose, ranking Web pages.

In order to show that his theory worked, Page developed a model search engine he called BackRub, in reference to its ability to follow hyperlinks back to other pages. At first, it searched a relatively limited number of pages, since it ran on Stanford University servers and as such did not have a great deal of hard drive capacity with which to work in the indexes. Even so, many webmasters did not appreciate the repeated visits by this experimental Web crawler, and some wrote angry letters to Stanford complaining about it. Fortunately, Stanford's computer science department was willing to assist Page.

As he developed the system, Page developed a friendship with fellow computer science student Sergey Brin, a Russian immigrant. Together they realized that this technology had vast commercial potential, and they decided that it was time to strike out on their own. In 1998, they met with Andy Bechtolsheim, one of the cofounders of Sun Microsystems, a major manufacturer of high-end computer workstations. Bechtolsheim was interested enough in their idea to write them a check, but for several weeks they had no company bank account into which to deposit the check. Meanwhile, Brin and Page frantically worked to put together the necessary paperwork to incorporate their company, Google, and put together the rest of the financing they would need to start their company. They moved their business office into a friend's garage in Menlo Park, California, joining a long tradition of garage-based start-ups.

PageRank Algorithm

When the World Wide Web was first developed, its critics called it a wonderful library with no catalog and no index. The criticism was not too far off the mark, for there were few ways to find a Web site if one did not already know about it or happen across a link on another page. Indexes and directories arose as people tried to gather links to the pages they found useful, but these were limited to sites their compilers knew about.

To resolve this problem, a number of companies developed search engines, including Web crawlers, programs that periodically searched the Web for new pages and indexed them to be searchable. Most of the early search engines determined the position in which each page appeared on their results by looking at the content of the page. In particular, it looked at description fields in the header, but it also indexed the words within the body text.

As the Web became increasingly commercialized in the second half of the 1990's, webmasters eager to improve their rankings in the search engine (and thus increase their revenue by getting more traffic) found ways to manipulate the search engines into giving them higher rankings than were really merited. Common tricks included repeating one's description multiple times in the header and setting large blocks of text in the same color as the background at the bottom of the body text, where it would be seen by the search engine crawlers but not the page's human audience.

When these questionable tactics led pages to rank high for commonly searched keywords that were in fact unrelated to the actual content of the page, users who arrived at them would often feel frustrated and betrayed, and they would typically blame the search engine. Larry Page, a computer science student at Stanford University, realized that it would be more effective to look not at the page itself but at the pages that had linked to it. Each link from an outside page could be considered a vote for the page's quality and usefulness. This was the principle behind the PageRank algorithm, the patented system behind Page and Sergey Brin's Google search engine. In addition, rewarding pages for obtaining links from other pages rather than solely for their own content would help to increase the hypertextual nature of the Web.

In the natural course of things, many webmasters also set to finding ways to manipulate the PageRank system, creating "link farms" to artificially create the image of a very popular site. However, Google has devoted considerable effort and energy to rapidly defeating such tricks in order to maintain the usefulness of the PageRank system.

By the end of the year, they were getting more than ten thousand search engine queries a day, and the press was taking notice of their work. The company had also grown to ten employees and was in need of real office space. For a time, they rented various offices in Palo Alto, California, but in 1999 they created a permanent campus in Mountain View, soon named the Googleplex.

The amusing name reflected a corporate culture that believed in the importance of humor. The office area was open, without cubicles to divide the space into little territories. Instead, employees were encouraged to move around and work with one another in informal groups that might develop and dissolve as projects emerged and were completed. State-of-the-art computers might be perched on desks made of old doors stretched over a pair of two-drawer filing cabinets. Employees could bring their pets to work, and several dogs were regularly seen roaming the campus.

Google focused on a clean site appearance with a minimum of distraction. The brightly colored Google logo above the search box lent it an air of childlike whimsy, and Page and Brin sought to instill a simple ethic upon their company: "Don't be evil." To set themselves apart from the multitudes of corporate executives who demand and collect hefty salaries, Page and Brin gave themselves a token salary of one dollar per year. Instead, for their income they would depend on the dividends derived from their substantial Google stock holdings, a move that reflected a public commitment to live or die by the success of their company.

Google has been quite successful. Although it produces no physical product and sells no advertising on its search pages, it has found a way to commodify the search process without compromising quality through its AdWords system. AdWords allows Web site owners to bid for top placement in various keywords or strings of keywords. Because advertisers want to get the most sales for their advertising dollar, they generally will concentrate their bidding activity on words and phrases that are particularly relevant to their product, rather than keywords that simply happen to be highly searched and thus very expensive.

IMPACT

Page's PageRank algorithm has made "Google" almost synonymous with "search engine." The search engines that were the mainstays of Internet searching before the rise of Google have shrunk to also-rans or disappeared altogether. The fact that "Google" has become a verb meaning to search the Web using Google is testament to the search engine's dominance.

—*Leigh Husband Kimmel*

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See also: Marc Andreessen; Tim Berners-Lee; Robert Cailliau; Vinton Gray Cerf; Philip Emeagwali; Robert Metcalfe.

CHARLES PARSONS

English engineer

Parsons is best known for his invention of the steam turbine. His vessel Turbinia, *the fastest ship in the world in 1897, demonstrated the power of the new technology, which was soon adopted by the Royal Navy and other navies.*

Born: June 13, 1854; London, England
Died: February 11, 1931; Kingston, Jamaica
Also known as: Charles Algernon Parsons (full name)
Primary fields: Mechanical engineering; naval engineering
Primary invention: Steam turbine

EARLY LIFE

Born in London, England, in 1854, Charles Algernon Parsons began his scientific training at an early age. His father was the noted astronomer William Parsons, the third earl of Rosse, who provided a comfortable upbringing and a scientific environment for his youngest son. Charles began his education at Trinity College in Dublin and later took a degree in mathematics at Cambridge in 1877. His distinguished father presumed that his son would follow in his footsteps and make a career in the sciences. Upon graduating, however, Parsons determined to step beyond the scientific shadow of his father and establish his own reputation in the scientific community.

Against his father's wishes, Parsons accepted an entry-level position at W. G. Armstrong, a major industrial concern whose products ranged from naval armaments to locomotives. Parsons learned a great deal about industrial construction at Armstrong before moving on to other positions at other industrial firms. He worked at Kitson's, a major locomotive manufacturer attempting to attract military contracts. Parsons helped to design an improved torpedo for the Royal Navy, but Kitson's could not persuade the navy to buy it. In 1884, Parsons became the chief electrical designer at Clarke, Chapman, and Company, a locomotive company that made engines for ships. There Parsons designed and constructed the first steam turbine.

LIFE'S WORK

In the late nineteenth century, steam engines were the main power source for most of the world. These engines harnessed steam produced in a boiler to push a series of pistons. Attached to a crankshaft, the pistons provided rotary power for a variety of machines that powered the Industrial Revolution. Steam engines had several problems, however. They were noisy and smoky. They were fuel-inefficient, with only a portion of the energy produced in the boiler used to push the pistons. The rest of the steam went up the smokestack. Steam engines were also bulky. The pistons needed a lot of space to cycle up and down, so the engineering sections on ships took up a large amount of space. The biggest problem, however, was that steam engines were mechanically unreliable. They required many moving parts connected by relatively delicate linkages to turn at thousands of rotations per minute. With such complexity, breakdowns were common and potentially hazardous. When steam engines failed, pieces tended to fly out of the engine. Reliability was also a concern for ship engines. If an engine failed on the high seas, a ship became stranded.

Parsons's new steam turbine solved all these problems. The mechanical device featured a driveshaft with metal blades attached like a huge fan. When steam from the boiler entered the engine, the steam pushed against the blades and turned the driveshaft. The turbine was smaller and lighter than existing steam engines and produced less smoke. Because the turbine spun in place, it took up less area than a typical steam engine, providing room for other things inside the limited space of the ship. It was also more efficient, because the steam could be recycled through the engine before it was released up the smokestack. Most important, the turbine was very reliable. The only moving part was the driveshaft, which meant that the engine could run for a long time without breaking down or requiring extensive maintenance. The turbine had an additional benefit in that an electric dynamo could be attached to the turbine, permitting the turbine to generate electricity as well.

Parsons established two new businesses to promote his inventions: C. A. Parsons and Company to promote his electrical concerns, and the Parsons Marine Steam Turbine Company to develop his new engine. He constructed a small test vessel, the *Turbinia*, to demonstrate the new engine. Parsons initially could not get *Turbinia* up to the speeds he expected because of cavitation—the formation of partial vacuums in water by a swiftly moving solid body—which occurred when propellers spun at high speed. He invented the cavitation tunnel, a device similar to a wind tunnel that allowed him to correct the cavitation problem. Finally operating at top efficiency,

THE STEAM TURBINE

Instead of being bulkier, heavier, and having more parts than its preceding technology, Charles Parsons's steam turbine was smaller, lighter, and simpler than the reciprocating steam engines it replaced. Because the turbine comprised little more than a series of blades arranged radially around a shaft encased in a housing, the engine required relatively few spare parts. The turbine did need a complex ball-bearing mounting to ensure that the shaft rotated smoothly. If the shaft did not rotate axially throughout its length, the momentum of the rapidly spinning shaft would cause a gyroscopic effect, wrenching the shaft out of alignment and causing massive damage to the engine. The risks were worth the effort, however, as the turbine did not totally make existing technology obsolete but instead complemented and improved it. The boilers that generated the steam for ordinary reciprocating engines were entirely sufficient to power the new steam turbines; thus, turbines made traditional types of shipbuilding better without making them obsolete. Because turbines were smaller than the older reciprocating engines, it was economically feasible to retrofit some ships with the turbine instead of rendering the ship obsolete or scrapping it.

The new turbines did require some advanced technology that earlier systems did not need. Turbine blades had to be strong but light, so metallurgical advances were necessary before Parsons's turbines became effective. The blades also needed extremely precise machine tooling, another technology necessary before turbines could exist. Turbines also required complex reduction gearing to transmit power to the propellers. Turbines revolved at thousands of rotations per minute, but the propellers only needed to turn at a few hundred rotations per minute. The reduction gearing transferred the torque of the rapidly spinning turbine shaft through a series of gears until the final gear, attached to the propeller shaft, turned at the required lower number of rotations per minute. The reduction gearing was so complex and required such precise machining that reduction gears failed far more often than the relatively simple turbines.

Turbinia could reach a speed of 34 knots, nearly ten knots faster than the swiftest ships at the time.

Parsons needed something to attract attention to his inventions, and he found it in the 1897 Naval Review. The Royal Navy hosted a gathering of British and foreign ships off the south coast of England every year. This naval review was special, however, because it also celebrated the Diamond Jubilee, the fiftieth year of Queen Victoria's reign, and the queen herself would be present. Parsons arrived without invitation at the naval review in the *Turbinia*. When Royal Navy ships tried to corner him, the *Turbinia* simply zipped away at high speed, and none of the steam engine-powered vessels could catch up. Parsons repeatedly piloted the *Turbinia* up and down the line of ships, and nothing could be done to stop him.

The navy was furious at Parsons's publicity stunt, but his demonstration did get the attention he sought. Two years later, the Royal Navy destroyers HMS *Viper* and *Cobra* were launched as test ships for Parsons's steam turbines. Parsons got an even bigger boost in 1905, when the Royal Navy announced that all of its future battleships would be turbine-powered. A year later, the revolutionary battleship HMS *Dreadnought* was launched. Powered by Parsons turbines, *Dreadnought*'s engines produced 22,000 shaft horsepower, driving the ship to a top speed of 21 knots, making *Dreadnought* the fastest battleship in the world. Following the Royal Navy's lead, other navies adopted the turbine, and Parsons's company profited handsomely from the foreign sales of its products.

Parsons soon had competition for the steam turbine market, however, and he spent much of the next decade defending his patents and firm from rival companies in Europe and the United States. The legal fights kept him away from his scientific research, and he made only relatively minor engineering breakthroughs for the rest of his career. Instead, Parsons purchased the Grubb Telescope Company, the largest manufacturer of large observation instruments, in 1925. The renamed Grubb-Parsons Company built most of the major observatory telescopes for the next thirty years.

For his accomplishments, Parsons received numerous awards. He was awarded the Royal Society's Rumford Medal in 1902, and he was knighted by King George V in 1911. In 1927, Parsons became a member of the Order of Merit, an esteemed honor conferred by the British monarch on citizens who have performed great service to the country. By royal decree, only twenty-four members of the Order of Merit can exist at any one time. Parsons spent his later years concentrating on electrical systems. Sir Charles Parsons died in 1931 at the age of seventy-six.

IMPACT

Parsons's turbines revolutionized naval warfare. His inventions were particularly vital at the turn of the twentieth century, as Europe was dividing itself into armed camps driven by international rivalry. The tensions in Europe would trigger World War I in 1914, a conflict in which battleships powered by Parsons's turbines played a significant role. The Royal Navy's decision to switch to turbine-powered battleships gave it an advantage over other navies that constructed only a relative few turbine-powered ships. Foreign navies, lagging behind in turbine technology, continued to build ships with the older piston engines that were prone to breaking down. England's turbine-powered ships, on the other hand, not only enjoyed a speed advantage over their rivals but also were more reliable during battle. After the war, the use of turbines in passenger ships made leisure travel safer and more efficient, and cruise ships enjoyed a boom in popularity in the 1920's and 1930's thanks to Parsons's invention.

—*Steven J. Ramold*

FURTHER READING

Appleyard, Rollo. *Charles Parsons: His Life and Work*. London: Constable & Co., 1933. The first major biography of Parsons after his death, this book is more of a celebration of the famed inventor than a critical biography. It is still an important work on Parsons's life because it contains the best description of his later, less well-known inventions. It also provides a good discussion of how Parsons's inventions changed how people lived at the turn of the twentieth century.

Roberts, John. *The Battleship Dreadnought*. Annapolis, Md.: Naval Institute Press, 1992. HMS *Dreadnought* was a revolutionary warship. While most historians concentrate upon its massive guns or thick armor, the most innovative feature of the ship was its turbine propulsion, the first in a battleship. This book devotes a full chapter to the design and installation of Parsons's turbines in *Dreadnought*, along with an evaluation of how the turbines performed compared to earlier types of engines.

Scaife, William G. *The Hon. Sir Charles Algernon Parsons (1854-1931): Scientific Engineer*. Dublin: Royal Irish Academy, 2002. As he was the son of Irish aristocracy, Parsons was eligible for membership in the Royal Irish Academy, an honor he received not long before his death. This publication, part of a series celebrating the history and honored membership in the academy, is one of the few recent accounts of Parsons's work.

Smith, Ken. *Turbinia: The Story of Charles Parsons and His Ocean Greyhound*. Newcastle upon Tyne, England: Tyne and Wear Museums, 1996. A full technological and industrial history of the design, construction, and operation of Parson's famed little ship. The *Turbinia* is on display in a Newcastle museum, and this book documents both the original construction of the ship, what happened to it after its research days were over, and the restoration effort to save the ship from destruction.

See also: Michael Faraday; Hero of Alexandria; Thomas Newcomen; James Watt.

BLAISE PASCAL

French physicist and mathematician

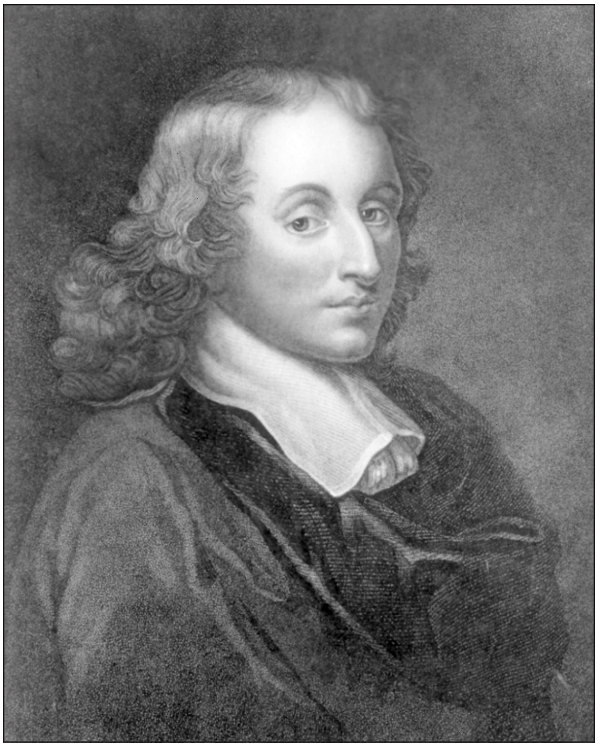
Pascal made important contributions to geometry, statistics, and probability theory. His work in physics led to the invention of the hydraulic press and the syringe, and to the modern understanding of the field of hydraulics.

Born: June 19, 1623; Clermont-Ferrand, France
Died: August 19, 1662; Paris, France
Primary fields: Mathematics; physics
Primary inventions: Hydraulic press; syringe

EARLY LIFE

Blaise Pascal (blayz pahs-KAHL) was born to Étienne and Antoinette Begon Pascal in Clermont-Ferrand, France. The family was well-to-do; the elder Pascal was a lawyer and judge. When the young Pascal was just three years old, his mother died. He was a frail and sensitive child whose health was always problematic. For this reason, his father insisted on educating the boy at home; by all accounts, Pascal's education was eccentric but resulted in his precocious accomplishments.

Pascal, his two sisters, and his father moved to Paris in 1631. At that time, his father gave up all of his outside work and devoted himself entirely to his intelligent young son's education. Pascal's studies included Latin, Greek, mathematics, and science. Although his father encouraged him to concentrate on Latin and Greek, Pascal proved to be particularly talented in mathematics



Blaise Pascal. (Library of Congress)

and the sciences. An apocryphal story suggests that when he was just twelve years old, Pascal arrived independently at Pythagoras's theorem of right triangles. Pascal's father was closely connected to some of the most important mathematical and scientific minds of his day, including Gilles Roberval, Girard Desargues, and Pierre de Fermat. The young Pascal was permitted to sit in on their discussions, greatly influencing his remarkable gifts in mathematics. Thus, although Pascal did not have any formal schooling, his education was of the highest order.

About 1639, Étienne Pascal unwisely became involved in political intrigue and nearly was sent to prison. Instead, in 1640, he was appointed tax officer in Rouen, and the family moved there. A rebellion among the poor in the area had resulted in the destruction of most of the records, and the senior Pascal was charged with overhauling the entire accounting system. The task was herculean, made even more difficult because French currency was not based on a decimal system. For three years, Blaise Pascal's father toiled away at calculations every day and far into the night. In sympathy, Pascal invented a calculating machine to help him with his work. In 1644, a Rouen artisan produced the first working model of the invention, and Pascal was later granted a patent for the machine. Although ingenious in construction and accurate in computation, the machine never enjoyed widespread use. The cost of construction made it prohibitive for all but the very wealthy.

Although it seemed clear that Pascal would have a lifetime career in mathematics and science, an event in 1646 changed the direction of his life. His father broke his leg in Rouen, and two brothers came to care for him. The brothers stayed with the family for three months and ultimately converted the entire family to Jansenism, a movement within Catholicism at odds with the prevailing Jesuit dogma. As a result of this conversion, and a second, more profound conversion experience in 1654, Pascal ultimately turned away from his scientific work and began instead to write religious and theological essays.

LIFE'S WORK

In terms of his scientific and mathematical life's work, Pascal achieved most of his accomplishments when he was quite young, although his most important works were not published until after his death. Pascal's work in physics had far-reaching ramifications for the modern world. About 1644, he became interested in experiments concerning vacuums conducted by the Italian Evangelista Torricelli, who invented the barometer. Pascal built on Torricelli's work by conducting a series of famous experiments with barometers. He constructed mercury barometers and had them taken to the top of a cathedral and to the top of a mountain. The results of his experiment demonstrated what is now known as atmospheric pressure. The same experiment also proved for Pascal that the empty space in the barometer above the mercury was a vacuum, something his contemporaries refused to believe could exist.

Pascal began writing a treatise on vacuums but did not complete the work. Around 1651, however, he completed two short treatises that would prove to be his most important contributions to the field of physics: *Traitez de l'équilibre des liqueurs, et de la pesanteur de la masse de l'air* (*The Physical Treatises of Pascal: The Equilibrium of Liquids and the Weight of the Mass of the Air*, 1937), published in 1663, a year after his death. The first treatise describes a complete system of hydraulics, something that had never been done before. The second demonstrates that nature's so-called abhorrence of a vacuum can be explained through the system of hydraulics. In the process of writing these treatises, he invented the hydraulic press and the syringe.

His work in mathematics is largely documented through correspondence with Fermat in 1654. Most notably, he developed what has come to be known as Pascal's triangle, or the arithmetical triangle, used in algebra and, more commonly, in probability theory. Pascal's triangle can be used to find combinations. In other words, the triangle can help solve the problem, "How many ways can one pick *x* objects from a set of *y* objects?" For example, one could imagine a set of five books. The question might arise, "What is the number of possible combinations of two books taken from this set?" Pascal's triangle quickly reveals the answer to be ten possible combinations. In games of chance, such as dice, the triangle can be used to predict the probabilities of particular throws. Pascal's work with this in mathematics and probability theory also set the scene for later developments in computational science, and ultimately, computers.

In 1656, Pascal had a religious experience that caused him to leave behind his scientific and mathematical work. During the last years of his life, he wrote the philosophical and religious treatises for which he subsequently became most famous. In 1656 and 1657, he published *Lettres provinciales* (*Provincial Letters*, 1657). The work was ostensibly a series of letters written by someone in Paris to a friend living in the country. In fact, it was a highly satiric and tightly written attack on many of the religious views of the day. The work angered the Jesuits and the king of France, who ultimately ordered the book burned. The book, however, enjoyed wide readership. Pascal also planned to write an apology for the Christian religion, a project he undertook beginning about 1657. He was not able to complete this project before his death; however, the section that he did complete, *Pensées* (1670; *Monsieur Pascal's Thoughts, Meditations, and Prayers*, 1688), is a beautiful and well-respected work.

Pascal died on August 19, 1662, after twelve months of painful illness. At the time of his death, he was very well known and highly respected for his mathematical and scientific accomplishments. Ironically, with the passage of time, *Pensées* has become his most famous work, enjoying a large readership well into the twenty-first century.

IMPACT

It is unusual to find one individual who so deeply influences spiritual and religious thinking as well as shapes the future of mathematical and scientific reasoning. Pascal did both, devoting his young life to scientific discoveries and inventions, and the remainder of his life to God. Because of his early work on vacuums and liquids, he virtually founded the modern study of hydraulics. By demonstrating how hydraulic pressure can multiply force, Pascal made possible such commonplace devices in the modern world as hydraulic brakes on airplanes and trucks, and syringes used in medicine. One of the most important inventions was the hydraulic press, a device that makes much modern manufacturing possible. The hydraulic press is used for forming metals or for any task that requires a great deal of force.

Pascal's memory continues to be honored in several fields. His name is attached to a common computer programming language. A "pascal" is also the name for the metric unit of pressure. Many high school and college mathematics courses discuss Pascal's triangle. Likewise, physics courses teach students about Pascal's law, a principle of hydrostatics. It is difficult to believe that a man

THE HYDRAULIC PRESS

Blaise Pascal's treatise on the equilibrium of liquids led to the formulation of what became known as Pascal's law. This theory states that a change in pressure on a fluid in a closed container will be carried without loss of pressure to every part of the fluid and to the walls of the container. The pressure is the same throughout the fluid and extends in all directions. Another way of saying this is that pressure throughout a closed system is constant. Further, when there is an increase in pressure on any point of the enclosed liquid, there will be an equal increase on every other point in the container.

This principle makes possible the transmission of force. Just as a lever can be used to move a very heavy object with less force than it would take to move the object without the lever, a hydraulic system uses a liquid, such as water or oil, to transmit force. To illustrate this point, one can imagine two connected cylinders: A one-square-inch cylinder on the left filled with fluid and a ten-square-inch cylinder on the right filled with fluid. Each is fitted with a piston. When a force of one pound is exerted on the smaller piston, it will lower the fluid ten inches. The pressure is then distributed throughout the entire system. That is, the pressure on one square inch on the left is distributed on each one-square-inch segment of the larger cylinder on the right. This pressure will result in lifting a ten-pound weight one inch. This is the principle on which a mechanic's automotive lift works: The transmission of force through liquid allows for a very heavy object (such as an automobile) to be lifted with much less force than it would take to lift the object directly.

who lived only to the age of thirty-nine, and who was sick for most of his life, was able to accomplish so much.

—*Diane Andrews Henningfeld*

FURTHER READING

Connor, James A. *Pascal's Wager: The Man Who Played Dice with God*. New York: HarperOne, 2006. In this readable book, Connor provides a clear context for Pascal's life, tracing the events of seventeenth century France. He explores both Pascal's scientific and religious life in a biography created for the general reader.

Hammond, Nicholas, ed. *The Cambridge Companion to Pascal*. Cambridge, England: Cambridge University Press, 2003. An excellent collection of essays by leading scholars on Pascal's life, accomplishments, and philosophy. Includes a useful chronology as well as an extensive bibliography. Particularly useful in the study of Pascal as an inventor are chapters on his work on probability by Henry Phillips; his decision theory by Jon Elster; and his physics by Desmond M. Clarke.

Krailsheimer, Alban. *Pascal*. New York: Hill and Wang, 1980. Short paperback covering Pascal's life and religious conversion. Also covers Pascal's scientific experiments in mathematics and technology, including his invention of the calculating machine and his papers on the equilibrium of liquids and the hydraulic press.

Shea, William R. *Designing Experiment and Games of Chance: The Unconventional Science of Blaise Pascal*. Canton, Mass.: Science History Publications, 2003. Focuses on Pascal's contributions to science and physics rather than on his religious and philosophical treatises. Describes the development of and the theory behind his calculating machine. Also provides extensive treatment of Pascal's treatise on the equilibrium of liquids, in which he provided a complete outline of a system of hydraulics.

See also: Charles Babbage; Otto von Guericke; Christiaan Huygens; Gottfried Wilhelm Leibniz; Sir Isaac Newton; Evangelista Torricelli.

LOUIS PASTEUR

French chemist and microbiologist

A pioneer in the field of microbiology, Pasteur established, on the most general level, what came to be known as the germ theory of disease. His studies of the way germs attacked the body led to important discoveries to prevent or lessen, through immunization, the dangers of many previously fatal diseases.

Born: December 27, 1822; Dôle, Jura, France
Died: September 28, 1895; Villenueve-l'Etang, near Saint-Cloud, France
Primary fields: Biology; chemistry; medicine and medical technology
Primary inventions: Pasteurization; immunization with vaccines for rabies and anthrax

EARLY LIFE

Louis Pasteur (LEW-ee pa-STUR) was born on December 27, 1822, in Dôle, a small city in the historic province of Franche-Comté in eastern France. His family descended from the traditional agricultural peasantry, but his father had shifted from farming to local artisanal work as a tanner. When the young Pasteur was encouraged by his teachers to prepare for examinations that would allow him to study in Paris, he initially hesitated.

Louis Pasteur. (Library of Congress)

PASTEURIZATION

The process known as pasteurization was initially developed in the early 1860's by Louis Pasteur in collaboration with the well-known physiologist Claude Bernard. Today, pasteurization is almost automatically associated with the conservation of milk, cream, and cheeses. Apparently, it was a later German chemist, Franz von Soxhlet (1848-1926), who was responsible for the widespread use of the pasteurization process for commercial dairy products.

When Pasteur carried out his pioneer work, the primary focus of concern was to prevent bacterial spoilage in commercially produced wines. Nonetheless, the principal processes involved are the same, whatever the edible product may be. Essentially, the aim of pasteurization is to reduce significantly the bacterial process associated with spoilage and, very importantly, to kill any pathogenic organisms that can spread diseases to the consumer of tainted dairy products. Two of the most dangerous diseases involved come from *Mycobacterium tuberculosis* and an infection caused by *Coxiella burnetii* commonly called Q fever. Other diseases that can be prevented by pasteurization are diphtheria, scarlet and typhoid fever, and strep throat.

Pasteur discovered that carefully controlled heating for an equally carefully controlled period of time can kill sufficient numbers (not all) of potentially pathogenic microorganisms in the organic substance in question. Pasteur proved that such reduced numbers of surviving bacteria do not constitute a real danger of infection if the product is refrigerated immediately and consumed within a certain period of time—within the expiration date on many commercial products today.

Equipment used to carry out the pasteurization has evolved considerably since the introduction of large vats that had to be heated for as much as thirty minutes. Modern devices have made it possible to treat large quantities with ever-increasing levels of efficiency. There are two widely recognized methods used in today's food processing industry. One process, known as high-temperature, short-time (HTST) pasteurization, involves passing raw milk products through a heating system that creates a uniform temperature of from 57° to upwards of 72° Celsius (about 135° to 162° Fahrenheit), holding that temperature for a period of at least sixteen seconds. Specific temperatures and timing can vary depending on the product being pasteurized. Extreme care must be taken to assure that heated batches do not intermix in any way with liquids coming into the treatment system. A second process, known as ultra-high-temperature (UHT) pasteurization, or asceptic processing, is more common than HTST methods in markets where refrigeration is less easily accessible. In this process, exposure to higher temperatures (91°-146° Celsius, or 195-295° Fahrenheit), which kills more microorganisms, is followed immediately by packaging in hermetically sealed containers. UHT products can be stored for long periods without refrigeration.

However, after his first exposure to a demanding academic environment in Besançon, the capital of Franche-Comté, he succeeded not only in going to Paris but also in gaining admission to France's most highly respected training school for teachers, the École Normale Supérieure. There, he concentrated his studies on chemistry rather than biology.

LIFE'S WORK

The professional career of Pasteur spanned nearly half a century. It began with his first rather brief appointment in 1848 in Dijon as a professor of physics at the lycée level. By 1849, he was named professor of chemistry, first at the University of Strasbourg, then at the University of Lille. These posts came after the wider scientific world of the time recognized the importance of his research in the area of crystallography. What he discovered in the mid-1840's was totally new: chiral molecules (that is, molecules that differ from their mirror image and cannot be superimposed as "twins") in the crystals of compounds usually produced from an organic "starter base." When Pasteur passed light through two crystallized compounds—one derived from organic matter, the other from inorganic chemical synthesis—he found that the latter were asymmetric (like right- and left-hand gloves), even though they were chemically identical to organically derived material. This discovery opened the door to a number of new scientific applications involving crystals.

At an early stage in the career that would earn him worldwide recognition, Pasteur's experiments focused on the issue of fermentation and conditions surrounding the genesis of microorganisms. Initially, there was a quite practical side to his work on fermentation, since the economically vital alcoholic beverage industries—both beer and wine—frequently lost a portion of their production when unpredictable souring occurred in their vats. When Pasteur took on the job of explaining this problem, he discovered that samples of bad beer contained both the yeast cells that spark fermentation and unwanted microorganisms that, as they multiplied in the liquid, became dominant, overwhelming the desirable bacteria needed for successful brewing. Pasteur's experiments that aimed at preventing this souring of beers and wines would form the basis of the later work with dairy products that gained him international fame: "pasteurization," or short-term moderate heating to kill off harmful microorganisms without destroying desirable ones.

Later stages of his work to protect key industries from contamination are associated with his years after 1857 as director of the scientific studies program at the École Normale Supérieure, where he had been a student himself in the mid-1840's. He discovered that a near-epidemic disease called pebrine, which prevented the hatching of silkworm eggs or killed young silkworms before they could produce the silk lining of their cocoons, was linked to transmission—via exposure of healthy silkworm eggs to "bad eggs" (often but not always eggs imported from abroad) that were carriers of dangerous microbes.

The key to preventing this presence of unwanted bacteria wherever their presence resulted in spoiling was to combine essential steps for maintaining sanitary conditions at every stage of handling any number of vulnerable organic products with the use of controlled levels of heat to destroy specifically identified bacteria in milk without harming the desired product itself.

Linked to this industrial phenomenon was the growing realization of the importance for medical doctors to use disinfectants to sterilize the entire local surrounding environment in order to prevent sepsis, the spread of bacteria from a point of infection to areas surrounding the infection. Application of disinfectants in hospitals, and particularly at the time of surgical operations, was quickly adopted by doctors. Although early guidelines for such preventive measures were based on Pasteur's findings, the name most often associated with the systematic use of disinfectants in hospitals is that of the Scottish surgeon Joseph Lister (1827-1912).

Pasteur's findings dispelled forever the "spontaneous generation" theory of germs, which held that the source of infection was in the organism from the outset. The extension of Pasteur's discoveries in the practical sphere of food conservation to the different subfields of microbiology would have a major impact on the scientific world's understanding of the transmission of infectious diseases. Most important, his studies of germ theory led him to develop the earliest vaccines, opening the field of immunization that became an important scientific tool for fighting disease in the twentieth century.

Pasteur's discoveries in the area of immunization began when he was studying fatal occurrences of anthrax, a disease that struck herds of both dairy and meat cows in many areas of Europe. He observed what he thought to be different levels of reaction to the disease among different animals in the same herd. He found through experiments that injection of live anthrax bacteria into the bloodstream of cows that had already contracted anthrax but had recovered did not seriously affect survivors. This discovery led to his supposition that injecting light doses of anthrax into healthy animals might lessen the severity of the disease if they contracted it later, or might even prevent infection altogether. Further tests proved his theory correct. Pasteur called the injection of such light doses of infectious bacteria into healthy organisms "vaccination" (from the Latin *vacca*, cow)—a gesture some think represented his recognition of earlier, similar work on cowpox by the British medical doctor and scientist Edward Jenner).

By the mid-1860's, Pasteur had returned to the University of Lille to serve as dean of the recently established faculty of science. His research there began to focus on infectious diseases in humans. A most significant breakthrough that would affect his international reputation came when he laid the basis for a rabies vaccine. His laboratory in Lille received public funds to support rabies research as early as 1867, but—somewhat surprisingly, perhaps, given Pasteur's skills in developing vaccines—his first use of the rabies vaccine with human subjects did not come until 1885, largely because of his collaboration with the medical doctor Pierre-Paul-Émile Roux, one of Pasteur's close colleagues and a major contributor (after 1887) to the newly founded Pasteur Institute in Paris.

Well before he succeeded in treating, and then—once a vaccine could be produced—taking measures for systematic prevention of the effects of rabies in humans, Pasteur spent considerable time experimenting with rabies in animals. Laboratory analysis had already localized the disease in the central nervous system of rabid dogs. Following the procedures he had pioneered in dealing with anthrax, Pasteur first extracted fluids from the spinal column of a rabid dog and produced symptoms of the disease in animals who had received injections of a reduced dosage. As his work progressed, the obvious became apparent: Rabies was transmitted via dog bites when the diseased animal's saliva entered the bloodstream of the victim. When it came to carrying out experiments with human patients, however, great care had to be taken. The first daring application by Pasteur (who was not himself a medical doctor and therefore not professionally qualified to treat patients) of the vaccine produced by Roux came in 1885, when a nine-year-old boy's life was saved after a daring decision to treat him with the rabies vaccine. Before long, news of the unprecedented event spread to many other countries, and requests soon came in for dissemination of Pasteur's findings—not only in the field of immunization but also in other fields—to the broader scientific world.

Various methods would be used to prepare vaccines, beginning in Pasteur's day with the same methods pioneered when he developed anti-anthrax serums: taking samples from the bodies of living infected animals. In the case of rabies, graphic descriptions exist of excruciating and dangerous procedures used to obtain samples from the saliva of rabid dogs. With time and expanding knowledge of chemistry, it became possible to build identical molecular structures of many vaccines in the laboratory, expanding the possibility of supplying medical laboratories all over the world.

A widely recognized monument to Pasteur's accomplishments remains the Pasteur Institute, a private nonprofit research institution with branches in many different cities in France and around the world. Originally founded in 1887, the institute combined closely related fields of specialization in microbiology with the practical concerns of medical doctors. The first such medical doctor was Jacques-Joseph Grancher, who was a specialist in the treatment of rabies. In its early years, the institute not only was involved with research but also established the first formal courses for students in the field of microbiology. Although Pasteur maintained a personal residence outside of Paris, it was a sign of dedication to his work that most of the last seven years of his life were spent in the private apartment within the original institute building. Since 1936, that building has housed a museum dedicated to his life work as well as a separate chapel where he was buried after his death.

From its quite focused beginnings under Pasteur, the institute would expand enormously during the twentieth century. Counted among the twelve research departments operating in the twenty-first century are Ecosystems and Epidemiology of Infectious Diseases, Parasitology, Neuroscience, and Virology.

IMPACT

Before Pasteur proved that hygienic prophylaxis could prevent diseases from establishing themselves in animals and humans, many biologists continued to subscribe to the idea of "spontaneous generation" of germs. Pasteur not only won this battle against archaic views of disease but also founded entirely new fields of preventive medicine: Pasteurization would obviously become a major procedure for processors of dairy products, and immunization an essential part of modern medical science. Pasteur's early work on vaccines, especially his rabies vaccine, might have been somewhat overshadowed in the twentieth century by vaccines that were developed against very widespread diseases like tuberculosis, diphtheria, tetanus, and yellow fever, but without his basic scientific contributions, such advances would have been delayed considerably.

—*Byron Cannon*

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See also: Gertrude Belle Elion; Edward Jenner; Jonas Salk; John Tyndall.

RUTH PATRICK

American botanist and limnologist

Patrick devised a method of assessing environmental pollution in freshwater lakes and rivers by measuring the presence of diatoms, or algae. She also developed a model for determining the health of a body of water; this ecosystem approach would thereafter be used routinely by scientists, environmentalists, and government researchers. Patrick became known worldwide for her pioneering work in limnology, or the study of freshwater biology.

Born: November 26, 1907; Topeka, Kansas
Also known as: Ruth Myrtle Patrick (full name)
Primary field: Biology
Primary invention: Diatometer

EARLY LIFE

Ruth Myrtle Patrick was born in Topeka, Kansas, on November 26, 1907, but spent almost all her early life in Kansas City, Missouri. Her father, Frank Patrick, who had majored in botany at Cornell University in Ithaca, New York, had become a lawyer and a banker only because his father was convinced that as a scientist he would not be able to support himself. However, Frank spent his spare time in the nearby woods collecting specimens. Often, he would take Ruth and her older sister, Catherine, along with him. When Ruth was seven, her father gave her a microscope, enabling her to look at the microscopic organisms, which would become her lifelong study. Even though at the time it was generally assumed that only men could be scientists, Frank always encouraged Ruth to pursue her interests. In fact, he would often tell her that she did not need to learn how to cook or sew; since she was going to be a scientist, he said, she could hire others to do those jobs. Ruth's mother, Myrtle Moriah Jetmore Patrick, shared her husband's belief that women should not be trapped in domestic duties. Her own passions were music and French. It is significant that her older daughter, Catherine, eventually earned a Ph.D. in psychology and became a women's rights activist.

After graduating in 1925 from the Sunset Hill School in Kansas City, Ruth took biology courses at the University of Kansas in Lawrence. However, the following year she transferred to Coker College, a small women's college in Hartsville, South Carolina. During summer breaks, her father arranged for her to take courses at Woods Hole Oceanographic Institute in Massachusetts and at Cold Spring Harbor Laboratory on Long Island, New York. In 1929, she received her B.S. degree in biology from Coker College. In 1931, she was awarded an M.S. degree from the University of Virginia. That same year, Patrick married Charles Hodge IV, an entomologist whom she had met at Cold Spring Harbor Laboratory, but at her father's request Patrick continued to use her maiden name. The couple moved to Philadelphia, where Hodge's family had lived for generations. Hodge joined the faculty of Temple University, where he would remain for more than thirty years. Meanwhile, Patrick worked on her own degree, and in 1934 she was granted a Ph.D. in botany by the University of Virginia. Her doctoral thesis was on the diatoms, or microscopic algae, of Southeast Asia.

LIFE'S WORK

In 1933, Patrick managed to obtain a position as a researcher at the Academy of Natural Sciences in Philadelphia. At the outset, she was told that because she was a woman, she would not be paid for her work. However, though she would not be put on the payroll until 1945, Patrick soon gained the respect of her male colleagues. In 1937, she was appointed associate curator of the Microscopy Department and curator of the academy's Leidy Microscopical Collection. Immediately, she began work on revitalizing the academy's research on diatoms. She organized the various collections into a Diatom Herbarium; she headed research expeditions that resulted in the addition of new specimens; and she updated both the indices of diatom species and the lists of publications on the subject.

Though Patrick had found the study of diatoms a highly effective way to assess pollution in freshwater, she now envisioned extending such an analysis to other creatures, including not just diatoms but also all the plants and animals living in a particular environment. This ecosystem approach, which became known as the Patrick principle, prompted her in 1947 to found a Limnology Department at the academy, which she chaired, while also serving as curator.

Though Patrick wanted to have a child, she worried that her busy schedule would interfere with parenting. However, she became convinced that it was quality time that was most important. In 1951, Charles Hodge V was born. It soon became obvious that like his parents, he was fascinated by science. When he was seven, his mother presented him with the same microscope her father had given her. Charles Hodge V went to medical school and became a pediatrician, specializing in gastrointestinal problems.

In the late 1940's, William B. Hart, an oil company executive, heard Patrick present a paper on her theories at a scientific conference and immediately hired her to pursue her experiments. One of Patrick's first projects involved applying the Patrick principle to research in the Conestoga River basin near Lancaster, Pennsylvania. The result was a landmark environmental study. Hart's high regard for Patrick helped her to acquire corporate funding for other projects, including a study commissioned by DuPont to assess the impact that the projected Savannah River Nuclear Plant would have on the Savannah River. In 1975, Patrick became the first environmentalist, as well as the first woman, on the DuPont board of directors. She remained a member of the Savannah River Site's Environmental Committee until 1997.

Over the years, Patrick has surveyed all of the rivers in the United States and many in other parts of the world. She estimated that her research has taken her to at least 850 rivers. She reported the conclusions she reached as a result of her studies in over two hundred scientific papers and in a number of books, including the multivolume series *Rivers of the United States*, which began to appear in 1994, and *Groundwater Contamination in the United States* (1987), which was coauthored by Patrick. Her preeminence in her field has brought her numerous honors. In 1973, for example, she was named the first female chair of the board of trustees of the Academy of Natural Sciences of Philadelphia, and in 1976 she was made honorary chairman of that same body. In 1973, she was named to the academy's Francis Boyer Chair of Limnology. She has lectured at Yale University and at the University of Pennsylvania and has received more than twenty honorary degrees and more than forty-five honors and awards. In 1970, she became the twelfth woman to be elected to the National Academy of Sciences. In 1991, the University of South Carolina-Aiken named the Ruth Patrick Science Education Center in her honor. In 1996, she received the National Medal of Science from President Bill Clinton.

Patrick's influence has been felt far beyond the academic community. The friendly relationships she maintained with corporate leaders have enabled her to secure funds for research, and she has managed to convince them that the environment faces real dangers and that as citizens they have a duty to limit or to eliminate damage to it. Patrick has also demonstrated a capacity to work well with government leaders. In 1966, she served on President Lyndon B. Johnson's Science Advisory Committee, Panel on Water Blooms, and in 1982 she was a member of President Ronald Reagan's Advisory Commission on Acid Rain. She also served on numerous other committees at the federal and state levels. In addition, Patrick has been active in environmental groups such as the World Wildlife Fund and the Nature Conservancy.

In 1985, Charles Hodge IV died. Ten years later, Pat-

THE DIATOMETER

Ruth Patrick's theory that water quality could be determined by studying diatoms led her to invent the diatometer. The device enables scientists to collect assemblages of diatoms at specific points in bodies of water so that the specimens can be analyzed for indications of algal responses to pollutants. Generally, the sites chosen are places where there is a considerable discharge of waste water into the larger body of water.

A diatometer is a floating rack with up to six slots in it, each of which will hold a glass microscope slide. Before the diatometer is assembled, the slides to be used are labeled and then cleaned, and from that point on they must not be touched except on the edges. The rack and the slides are then transported to the project site, where the diatometer is assembled. However, before it is installed, it is essential that the flow velocities at the study site are checked, so that the diatometer will be moored firmly enough not to break loose. Sometimes anchors are used to keep the instrument in place; at other times, it is attached by ropes to trees or pilings. There are several other considerations in the placement of a diatometer. It must be in deep enough water so that it can float freely; there must be no danger of it touching bottom; and it should be in direct sunlight, at least for part of each day. A diatometer is usually left in place for about fourteen days, which is a long enough period for the diatoms on the slide to develop fully. In some studies, a series of diatometers is placed at a single location, so that changes over time can be observed; in others, a number of diatometers are positioned near each other and are later removed at the same time.

Researchers throughout the world now use diatometers to check freshwater bodies for pollution. Their conclusions enable government officials to make decisions that will preserve the aquatic ecosystems—for example, by banning the release of certain pollutants into waterways or by setting limits on others.

rick married Lewis H. Van Dusen, Jr., a Philadelphia lawyer and a family friend. On November 17, 2007, the Academy of Natural Sciences held a gala to celebrate Ruth Patrick's upcoming hundredth birthday.

IMPACT

Patrick devised ways to test the pollution levels of freshwater bodies, notably by inventing the diatometer and by formulating the Patrick principle, both of which became standard tools for researchers. Moreover, through the years she taught her theories and her methods to hundreds of students and mentored many future scientists. Patrick always stressed teamwork, not only making sure that students with a single specialty worked together but also ensuring that every project involved specialists trained in different disciplines—botany and biology, for example—and even chemistry and physics. Thus, she put the Patrick principle into practice, and the success of the Conestoga River study proved how effective her approach was. Necessarily, experts in many different areas made Patrick's Limnology Department their academic home, and soon the department became known for what was then an unusual practice, multidisciplinary research.

Patrick's books and her many scientific papers turned the attention of other scientists to long-neglected dangers to the environment, such as freshwater pollution. However, Patrick's influence did not stop with the academic community. Through her personal contacts with leaders in business and industry and with elected officials, she has played an important role in raising their awareness of ecological issues and in persuading them to develop effective environmental policies.

—Rosemary M. Canfield Reisman

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See also: Jacques Cousteau.

LES PAUL

American guitarist

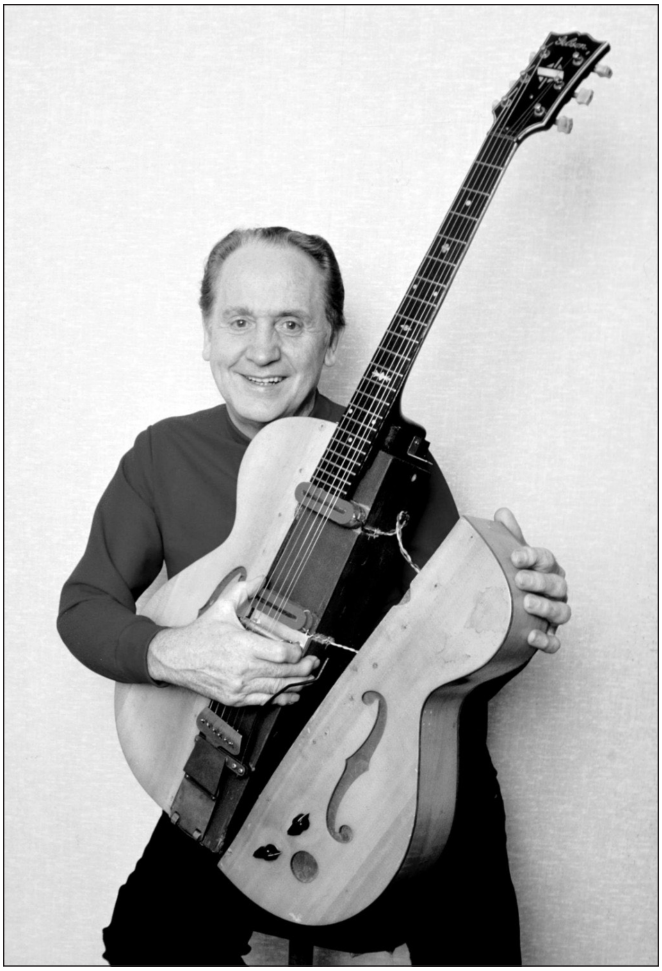
In addition to inventing the kind of solid-body electric guitar that made rock music possible, Paul developed a number of unusual recording techniques that are now standard in the recording studio, such as sound-on-sound, overdubbing, and tape delay.

Born: June 9, 1915; Waukesha, Wisconsin
Died: August 13, 2009; White Plains, New York
Also known as: Lester William Polfuss (birth name)
Primary field: Music
Primary inventions: Solid-body electric guitar; multitrack recording

EARLY LIFE

The father of the modern electric guitar was born Lester William Polfuss in Waukesha, Wisconsin. His father, George, left home when Les was eight, estranged partly by his wife Evelyn's radical communist politics. Evelyn became a doting "stage mother" to young Lester, indulging his passion for music. When he brought home a harmonica given him by a ditch digger, Evelyn boiled it before his son put it to his mouth—unintentionally making the reeds capable of the bluesy sound Les would come to emulate. When he finally picked up the guitar four years later, the twelve-year-old Les was fascinated with WLS radio star Pie Plant Pete, who met Les at a concert and showed him how to finger the guitar. Within weeks, Les had mastered Pete's repertoire and was soon imitating it on rival station WJJD. Calling him "Red Hot Red," Evelyn Polfuss found him gigs at PTA meetings, and he would sneak into speakeasies at night. By the summer of his junior year, 1932, he was on the road with a picker named Sunny Joe Wolverton and left school to play with him on KMOX in St. Louis, then the seventh-largest city in the United States. The partnership only lasted two years, by which time Les was listening to and imitating jazz in Chicago, as well as building pickups for his first experiments in electric guitars.

Paul began playing in Chicago with Jimmy Atkins, older brother of later guitar legend Chet Atkins. In 1938, Paul made the jump to network radio with Fred Waring and his Pennsylvanians, forming a side act with Atkins on acoustic guitar and Ernie Watkins on bass, under the name of the Les Paul Trio. In the midst of traditional studio recording sessions with his trio at that time, Paul experimented at home in his garage studio, recording different parts at different speeds and editing them together. He was on the verge of inventing techniques that would revolutionize the recording industry.



Les Paul with "the Log." (Getty Images)

LIFE'S WORK

While neither of the inventions for which Les Paul is most famous—the solid-body electric guitar and magnetic tape overdubbing—were totally original with him, he was, like most innovators in the electronics field, a creator of something distinctive and influential built on existing technology. In the crudest sense, however, Paul has as early a claim as anyone to the invention of the electric guitar, since he improvised one while playing for tips in the parking lot of Beekman's Barbecue Stand in Waukesha in 1929, at the age of fourteen. Adolph Rickenbacker (1886-1976) is usually credited with the first electric guitar, in 1931, but his was based on the same hollow body as acoustic guitars. By the end of the 1930's, Rickenbacker was also marketing a solid-body electric guitar, and Leo Fender (1909-1991) was experimenting with similar designs when, in 1941, Paul first demonstrated his design. It was nicknamed "the Log" because it was simply a block of wood the width of a fretboard, to which were attached the two halves of a traditional hollow-body guitar. The solid wood core prevented the insides of the body from acting as a sounding chamber.

Paul brought his design to the Gibson Guitar Corporation in Nashville, Tennessee, in hopes of interesting the manufacturer in producing his design. Gibson was not interested—until its rival Leo Fender showed how lucrative the electric guitar market was with the introduction of the Broadcaster (later the Telecaster) solid-body electric in 1950. Hiring Paul as a consultant, Gibson president Ted McCarty designed a solid-body guitar that he named the "Les Paul" and contracted Paul's endorsement. Paul and his fans have often exaggerated his role in the development of the Gibson Les Paul, but at the first meeting between McCarty and Paul in the fall of 1951, McCarty already had a prototype. Paul did, however, contribute one element to the design. His only suggestion regarding the prototype was that it incorporate the sort of tailpiece he had pioneered on the Log that gave him the muting sound Paul had made famous. It had a trapeze-shaped bar below the strings. It was fitted into Gibson's design, and the Gibson Les Paul was born.

There is little mystery about why Gibson wanted Les Paul to be part of its name brand. In 1951, Paul was not only the top guitarist in the world (both in sales and in the *Down Beat* polls) but also one of the top-selling recording artists of any type. The Les Paul-Mary Ford version of "How High the Moon" spent nearly half the year (twenty-five weeks) on the *Billboard* charts, nine weeks of that time in the number one spot. On August 25 of that year, *Billboard* magazine announced that the duo became the first act in history to have four hits simultaneously in the famous Top 40. Paul and Ford (his wife) ended 1951 tied with Patty Page for best-selling recording artists (they even sang some of the same songs). Paul and Ford had more Top 10 hits in 1951 than Bing Crosby, Frank Sinatra, and the Andrews Sisters combined.

One of the keys to the success of those recordings was another series of Les Paul inventions: overdubbing, tape delay effects, and multitrack recording. In 1948, Paul was playing on Bing Crosby's radio show when Crosby bought the first mass-produced tape recorder in America, the Ampex Model 200. Fascinated with Paul's experiments with double-tracking and overdubbing on wax disks, Crosby gave Paul an Ampex 200 and encouraged him to continue. Paul added a second recording head, slightly misaligned, allowing two tracks to be recorded on the same tape. Crosby at the time was recording with the top female harmony recording group, the Andrews Sisters. Paul, who had recorded with the Andrews Sisters, realized that his wife could sing all three harmony parts with his multitracking technique. He had already been using it on multitrack disk to record multiple guitar parts, playing some back at different speeds, allowing his already-fast picking technique to appear superhumanly faster ("Lover," 1947). Putting the two together produced the stunning effects that propelled "How High the Moon" to number one.

Paul understood, more than the marketing executives at Capitol Records did, how much of the appeal of these multitracked recordings was due to their "modern" sound. However, instead of putting this modernity across with hip, modern compositions—these were the waning years of the big band era, and Elvis Presley had not yet appeared—Paul stunned listeners with up-tempo, electrified versions of old-fashioned hits, including covers of the 1918 jazz classic "Tiger Rag" (Paul's first recording with the Gibson Les Paul) and Al Jolson's 1926 hit "I'm Sitting on Top of the World," which *Variety* identified as the thirteenth consecutive Paul-Ford single to sell half a million copies.

THE LOG

In 1941, Les Paul convinced the management of the Epiphone Guitar Company to allow him to use its West 14th Street factory after hours to test some of his theories of guitar construction. The Epiphone he used at the time was one of the first electric guitars, but Paul objected to two of its acoustic qualities: first, the hollow body created a resonance that caused feedback with the amplified sounds; second, it dampened the vibration of the strings so that the guitarist could not sustain a note. In the Epiphone machine shop, he solved both problems by bolting a sheet of metal across the S-shaped holes on the body. Paul realized that he was retrofitting, however: He had learned enough about engineering to understand that even the solid-body guitars of the time, Rickenbacker and Fender, mimicked the shape that the acoustic nature of the traditional guitar required but the electric guitar did not.

Understanding that shape did not affect the sound, which came from the electrical connection, the pickup, Paul took a plain four-inch-square post and attached the neck of a Gibson guitar. The fingerboard came from a Larson Brothers guitar. Two decades before Jimi Hendrix and Jimmy Page achieved amazing vibrato effects with what the sixties called a "whammy bar," Paul designed a similar tremolo arm—in the forties it was called a "vibrola," a lever attached to the tailpiece that allowed him to vary the tension of the strings. Instead of commercial pickups, Paul used coils from an electric clock.

The finished product looked more like a fencepost than a guitar. M. H. Berlin, president of Gibson Guitar's parent company, called it "a broomstick with a pickup" when Paul showed it to him, hoping Gibson would manufacture it. Berlin declined the offer, perhaps postponing by a decade the creation of the Gibson Les Paul guitar. Dubbed "the Log," Paul's invention did not look much like a guitar, though Paul sometimes attached wings fashioned from two halves of an acoustic guitar. The few times he played it in live gigs, however, he removed them for the shock value of the unconventional appearance. In 1990, the Log was donated to Nashville's Country Music Foundation Museum, where it quickly became one of the most popular exhibits.

IMPACT

No electric guitarist has been more influential on popular music—rock, country, and jazz—than Paul. Furthermore, the recording techniques he pioneered—tape delay, sound-on-sound, multiphasing, and multitracking—became standard in the studio. Multitrack recording, in fact, became virtually universal, even when an artist was not playing multiple instruments. Paul even invented the mechanical means by which multitracking became possible, when he modified an Ampex 200 by adding a second recording head. His design experiments on the solid-body electric guitar were vital to its development, even if his claims as an inventor are not fully granted, because he combined experiments in performance with experiments in guitar construction.

In 2003, *Rolling Stone* magazine rated the top guitarists of all time, and Les Paul was ranked number 46. Many of the top guitarists of the time objected, arguing that his rating should be higher because of his massive influence and sheer longevity. In 2006, at the age of ninety, Paul won two Grammys for his album *Les Paul and Friends*. In the summer of 2008, Discovery World in Milwaukee opened a museum exhibit featuring his contributions to the electric guitar and the recording industry. Paul died on August 13, 2009, at the age of ninety-four.

—*John R. Holmes*

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See also: Marvin Camras; Ray Kurzweil; Hugh Le Caine; Robert Moog.

GERALD PEARSON

American physicist

Besides playing a supporting role in the invention and improvement of the transistor, Pearson worked with two other principal researchers at Bell Telephone Laboratories to invent the photovoltaic cell, commonly known as the solar cell, which uses sunlight to generate electricity.

Born: March 31, 1905; Salem, Oregon
Died: October 25, 1987; probably United States
Also known as: Gerald Leondus Pearson (full name)
Primary fields: Electronics and electrical engineering; physics
Primary invention: Photovoltaic cell

EARLY LIFE

Gerald Leondus Pearson was born in Salem, Oregon, on March 31, 1905, to David Shafer Pearson and Sarah Allen Pearson. When he finished high school, he stayed in his hometown to enroll at Willamette University, from which he received a bachelor's degree in physics and mathematics in 1926. During the next academic year, he taught at a high school and then, in 1927, enrolled at Stanford University, near Palo Alto, California. At Stanford, he majored in physics, carried out experiments with X rays, and earned a master's degree in 1929. On June 30 of that year, in Rosedale, Oregon, he married Mildred Oneta Cannoy (1906-2000). The newlyweds soon moved to New York City, where Pearson began work for Bell Telephone Laboratories, initially concentrating on reducing electronic noise and then on developing thermistors, which are resistors that show special sensitivity to temperature. During World War II, he carried out research with a friend and fellow physicist at Bell Labs, Walter H. Brattain, on infrared detectors for U.S. military use.

LIFE'S WORK

By 1945, Pearson, Brattain, and other scientists and engineers were working at the new Bell Labs campus in Murray Hill, New Jersey. Pearson shared an office with Brattain, who smoked cigars with him, and both men joined the research group for semiconductors when the war ended in August. In October, 1945, John Bardeen, another physicist, joined them. Their supervisor was the physicist William Shockley, brilliant but sometimes abrasive.

In its efforts to develop a solid-state amplifier to replace the commonly used vacuum tube, the research group soon concentrated on the semiconductors germanium and silicon, and through experiments Pearson learned how impurities in crystals of those elements affect the flow of electrons and holes (absences of electrons) in the crystals. In addition, he worked with Brattain to try to produce the electric field effect that Shockley had predicted in April, 1945; that is, Pearson and Brattain tried to use an external electric field to control the flow of holes and electrons in very thin layers of semiconductors.

Early in the spring of 1946, Pearson and Brattain had a slight success in creating a field effect in germanium when they used liquid nitrogen to reduce its temperature drastically. In December, 1947, about the time Brattain and Bardeen invented the point-contact transistor (a solid-state amplifier using point contacts), Pearson had a greater success in creating a field effect by using a suggestion from Shockley. On a plate of quartz, Pearson placed a film of positive-type, or P-type, germanium (germanium in which an impurity has produced an excess of holes). With a wire attached to each end of the germanium-coated plate and a little drop of the electrolyte glycol borate on the germanium, he used a wire touching the drop to apply a small voltage, which

THE PHOTOVOLTAIC CELL

In 1839, Alexandre-Edmond Becquerel discovered the photovoltaic effect in general by exposing a particular solution to light and noticing an electric current, and in 1873 Willoughby Smith discovered the effect for selenium. Beginning with Russell Ohl's discovery in 1940, silicon has proved itself an especially suitable semiconductor for a photovoltaic cell. An individual silicon atom has fourteen protons (each positively charged) in its nucleus, as well as fourteen electrons (each negatively charged) in its electron shells. In the outer shell, there are four electrons and four holes where electrons could be. Within a crystal, each silicon atom bonds with four other silicon atoms, with which it shares electrons.

Boron, with just three electrons in its outer shell, can be used to dope a crystal of pure silicon and, by introducing holes (absences of electrons) into it, turn it into positive-type (P-type) silicon—although in isolation the crystal as a whole remains uncharged because its number of electrons equals its number of protons. Comparably, phosphorus, with five electrons in its outer shell, can be used to dope pure crystalline silicon and, by introducing electrons that do not fit into the crystal lattice, turn it into negative-type (N-type) silicon—although, again, in isolation the crystal as a whole remains uncharged because of the equal number of protons and electrons.

When manufacturers form a PN junction by creating P-type silicon on one side of a wafer and N-type silicon on the other side of the same wafer, electrons flow from the N-type silicon to the P-side of the junction, creating a net negative charge there, and holes flow from the P-type silicon to the N-side of the junction, creating a net positive charge there. When a sufficiently energetic photon (quasiparticle) of light hits an electron on the P-side of the junction, the electron receives energy from the photon. Hardly being able to go farther into the P-side of the junction because of the negative charge there, it returns to the N-side, where it has a significant chance of getting into a conducting channel built into the surface and passing through a circuit, thus helping to provide electric power. While the light shines, the process keeps going with billions upon billions of electrons. Combining photovoltaic cells in series within a frame to form a photovoltaic module (a solar panel), manufacturers have provided a technological means through which the Sun works directly for humankind.

changed the current in the film significantly. He recorded his success in his laboratory notebook with an entry dated December 12.

On the afternoon of December 23, Pearson spoke briefly at the first presentation to high-level Bell Labs executives of Brattain and Bardeen's solid-state amplifier. After his talk and the others were over, Pearson and his fellow researchers witnessed the first formal demonstration of this device, this first transistor. Less than three days later, on the snowy morning of December 26, Pearson achieved the field effect without using glycol borate. Using a thin piece of mica with gold on one side and germanium on the other, he applied a voltage to the gold and thus produced a small change in the current in the germanium.

Regrettably, the invention of the point-contact transistor led to a troublesome situation for researchers, such as Pearson, in the semiconductor group. Shockley was too competitive to be entirely happy that Bardeen and Brattain had invented the device without his own close involvement. Furthermore, the discovery that the little-known physicist Julius Lilienfeld had already patented a device depending upon the electric field effect meant that Shockley's name could not legitimately be on the patent for the point-contact transistor. Pearson avoided taking sides personally in the dispute, but his work pushed him toward Shockley professionally. The issue of *Physical Review* dated July 15, 1948, contained Shockley and Pearson's article "Modulation of Conductance of Thin Films of Semi-Conductors by Surface Charges," which derived from Shockley's theory and Pearson's experiments. The two articles by Bardeen and Brattain in the same issue, however, became more important.

With his laboratory skill, Pearson helped Shockley improve the transistor. Building on an experiment performed at Bell Labs by Richard Haynes, Pearson learned how to make very narrow filaments of germanium. Those filaments would let holes or electrons flow with some ease but would nevertheless control the flow. The intent was to lessen electronic noise by doing away with at least one of the metal points of the point-contact transistor. By the middle of August, 1948, Pearson, Shockley, and Haynes had built a filamentary transistor in which only one point contact remained. In a sign that hard feelings lingered between Brattain and Bardeen, on the one hand, and Shockley, on the other, the two direct inventors of the point-contact transistor did not work on the filamentary one. Furthermore, in a reorganization at Murray Hill in the spring of 1951, Brattain and Bardeen joined the physics of solids research group, while Pearson joined the transistor physics research group, led by Shockley.

Pearson therefore played an important part in the development of Shockley's junction transistor, which Bell Labs announced to the public on July 4, 1951. Depending not at all on point contacts but, in its developed form, on a sandwich-style arrangement with positive-negative junctions, or PN junctions, the junction transistor soon led to the photovoltaic cell, or solar cell, which contains only one PN junction. Actually, Russell Ohl, another Bell Labs colleague, had noticed a strong photovoltaic effect in 1940 when he had shone a flashlight on a silicon rod. Mastery of the manufacture of uniform and pure silicon crystals, however, was necessary for the development of practical photovoltaic cells, as was mastery of doping, the careful contamination of the silicon with certain elements to make it electrically either P-type or N-type.

While researchers at Bell Labs were working successfully at improving techniques for making and doping silicon crystals, Daryl Chapin worked there trying to develop an efficient photovoltaic cell that would use the Sun's energy to power telephones where no other reliable power was available. In 1952, Pearson was working nearby with Calvin Fuller to build a silicon rectifier to convert alternating current to direct current. To increase conductivity, Fuller doped the silicon with gallium. Then Pearson dipped the gallium-doped silicon into heated lithium. Afterward, he found that, when he exposed the treated silicon to light, it produced an electric current, and he quickly told Chapin. After further work by the three researchers improved the efficiency to Chapin's goal of 6-percent efficiency, Bell Labs announced the invention to an appreciative public on April 25, 1954.

Pearson remained at Bell Labs until he retired from the company in 1960. In September of that year, he became a professor of electrical engineering at Stanford, where he worked at his own research, especially on compound semiconductors, and helped his students with theirs. Even after his formal retirement from the faculty in 1970, he remained active in research for years. By the time he died, on October 25, 1987, he had earned numerous honors and the respect of physicists and electrical engineers around the world. His wife and two children survived him, as did grandchildren and great-grandchildren.

IMPACT

Unlike Shockley, Bardeen, and Brattain, Pearson never received a Nobel Prize. Nevertheless, along with them, Chapin and Fuller, and other researchers at Bell Labs, Pearson contributed enormously to electronic technology. In peace or at war, at home or in the office, or on the road between, people in highly developed countries and often in underdeveloped ones depend on instruments containing descendants of the junction transistor that Pearson helped develop. Complex machines such as automobiles, airplanes, and digital computers, all of which existed before the transistor, have come to rely on what Pearson helped bring into the world. As for the photovoltaic cell, it gained use quickly not only for powering telephones in remote places but also for powering satellites orbiting the Earth. By the early twenty-first century, photovoltaic cells produced the electric current for the transistors within the pocket calculator and, on a larger scale, provided the electric current that powered some houses. In the opinion of numerous engineers and scientists, photovoltaic cells promised to yield environmentally harmless energy for everything from the lamps bordering a driveway to the car in it and the building at the driveway's end.

—*Victor Lindsey*

Further Reading

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Goetzberger, A., and V. U. Hoffmann. *Photovoltaic Solar Energy Generation*. New York: Springer, 2005. A monograph that presents not only technical information about the generation of electricity through the use of sunlight but also an economic argument to support solar power. Illustrations, bibliography, index.

Ramsey, Dan. *The Complete Idiot's Guide to Solar Power for Your Home*. Indianapolis, Ind.: Alpha Books, 2003. Despite the title, a solar enthusiast's advice and practical information for the intelligent nonspecialist who wishes to build, buy, live in, or sell an energy-efficient, solar-powered house. Illustrations, glossary, appendix, index.

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Wenham, S. R., M. A. Green, M. E. Watt, and R. Corkish. *Applied Photovoltaics*. 2d ed. Sterling, Va.: Earthscan, 2007. A textbook for electrical engineers, solid-state physicists, and other appropriately educated persons interested in the details of converting the Sun's energy into electrical energy. Illustrations, exercises, bibliographies, appendixes, index.

See also: John Bardeen; Willard S. Boyle; Walter H. Brattain; Calvin Fuller; William Shockley; Maria Telkes.

John Stith Pemberton

American druggist

As an effort to provide Civil War veterans with a commercial pain reliever less addictive than available opiates, Pemberton's formula was not successful. As a soft drink under the name of Coca-Cola, it became the world's best-selling beverage.

Born: July 8, 1831; Knoxville, Georgia
Died: August 16, 1888; Columbus, Georgia
Primary field: Manufacturing
Primary invention: Coca-Cola

Early Life

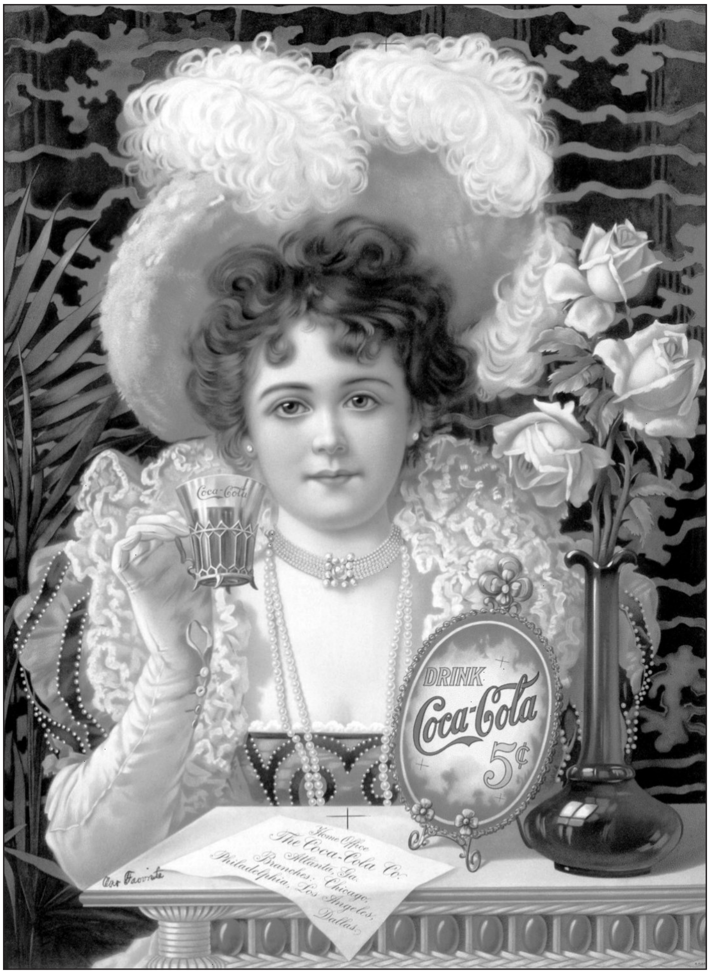
John Stith Pemberton was born in Knoxville, Georgia, but his family moved to Rome, Georgia, in his childhood. In 1848, Pemberton enrolled in the Southern Botanico-Medical College of Georgia in Macon, and he received his degree in 1850. His training was mostly in herbal cures, and upon graduation he set up a chemical laboratory where he produced patent medicines. He also, at this time, took a degree in pharmacy. In 1853, he married Ann Eliza Clifford Lewis, and together they moved to Columbus, Georgia, where he established a wholesale drug business. On January 19, 1861, as the nation entered the Civil War, Georgia became the fifth state to secede from the Union, and Pemberton enlisted in the Third Georgia Cavalry Regiment, rising to the rank of lieutenant colonel.

On Easter Sunday, 1865, Colonel Pemberton was wounded in the defense of Columbus. It was in the treatment of this wound that Pemberton was given the morphine to which he would remain addicted the rest of his life. Moving his family to Atlanta, Pemberton created what was perhaps the most advanced chemical laboratory of his day, not only producing the patent medicines he had developed in Columbus but also testing soil and chemical fertilizers for the state of Georgia. The lab he established, now a part of the Georgia Department of Agriculture, is still in operation. One of his products, an imitation of French coca wines (wines laced with a distillate of the coca leaf), was promoted as a headache cure. Pemberton used it himself for that purpose. When Atlanta became a "dry" city in 1886, outlawing the consumption and sale of alcohol, Pemberton appealed to the growing temperance movement by replacing the wine in his formula with sugar water. Combining the coca leaf extract (a source of cocaine) with the kola nut (a source of caffeine), Pemberton produced a drink without the slightest trace of alcohol that also functioned as a stimulant.

Life's Work

The mixture of kola nut and coca leaf was not Pemberton's invention. Angelo Mariani and Company Vintners of Paris developed a Bordeaux wine with coca and kola known as Vin Mariani. In March of 1885, Pemberton advertised his own version of the laced wine, asserting its superiority to Mariani's. Coca had been the nineteenth century methadone: Civil War veterans, including Pemberton, injected cocaine in the vain belief that it might cure morphine addiction, which was so common among veterans that it was referred to as "the Army disease." Some physicians warned, correctly, that the dangers of cocaine addiction were as real as those of morphine, but Pemberton denounced those fears in the press. Even before July 1, 1886, when Atlanta went dry (prohibiting the sale or consumption of alcohol), Pemberton knew that the Reverend Sam Jones's temperance movement was making wines hard to market in his city. Consequently, he spent that winter and spring experimenting with a "temperance drink" with coca, kola, and an aphrodisiac called "damiana." He would concoct formulas in his laboratory, then send them to Willis Venable, who operated a soda fountain at Jacob's Pharmacy, for his customers to try.

As a chemist, Pemberton knew that caffeine was the active ingredient in the kola nut, and that it was more commonly derived from coffee and teas. He was convinced, however, that the caffeine from the kola nut, isolated by Merck laboratories in Darmstadt, Germany, was superior and nonaddictive: He said so in a paper he delivered to the Georgia Pharmaceutical Society in April of 1886. In the same paper (read for him at the convention by a colleague, since Pemberton could not tear himself away from his beverage experiments), Pemberton extolled the virtues of the coca leaf, and he emphasized, as Angelo Mariani had with his coca wines, that the preferred Peruvian coca leaves were those with smaller amounts of cocaine, but with other alkaloids present.



A Coca-Cola magazine advertisement from the 1890's. (Library of Congress)

COCA-COLA'S SECRET FORMULA

In a five-page appendix to his book on Coca-Cola, *For God, Country, and Coca-Cola* (2000), Mark Pendergast details the fortuitous coincidence by which he stumbled upon John Stith Pemberton's original recipe, and he gives the world's most secret formula in its entirety. Pemberton's original formula book was apparently kept by his apprentice, John P. Turner, who opened his own pharmacy in Columbus, Georgia. In 1943, Turner's son gave it to the Coca-Cola Company, who carefully removed the page labeled "Coca-Cola."

Pendergast, however, found another page with Pemberton's original formula, which had escaped notice because it was headed only with an *X* at the top of the page. There is no mention of the kola nut, which is surprising considering the emphasis Pemberton placed on that ingredient. The first ingredient listed, however, is "citrate caffein" (1 ounce), which is surely the kola nut extract produced by Merck, which Pemberton lauded in 1886. Next is vanilla extract (1 ounce). The third ingredient is merely listed as "flavoring," but the flavors are listed at the bottom of the recipe: oil orange, oil lemon, oil nutmeg, oil cinnamon, oil coriander, and oil neroli, dissolved in alcohol and left to stand for twenty-four hours. The remaining ingredients are fluid extract of coca (4 ounces), citric acid (3 ounces), lime juice (1 quart), sugar (30 pounds), water (2.5 gallons), and "caramel sufficient"—that is, enough to color the mixture.

The flavoring mixture was the key to the "secret formula" mystique after Pemberton's death. Asa Candler, who bought the Coca-Cola Company in 1892, made this list of essential oils top secret and saw to it that all these items were stripped of their labels as soon as they arrived. Candler code-named the flavoring formula "7X" (for the seven ingredients listed above, including the alcohol in which the mixture is dissolved). By the time this formula was back in the Coca-Cola Company archives in the 1940's, citric acid had been replaced in the mixture by phosphoric acid. Also, because the addictive nature of caffeine was well known, the amount of caffeine was reduced (and caffeine-free coke became available in the 1980's). It is likely that Pemberton's original formula is the one Pendergast found, and it is the one given here.

About that time, in April, Pemberton announced that he had perfected his formula, but he needed a name for it. Since alliterative names were the norm for patent medicines at the time, Pemberton's partner Frank Robinson suggested naming it after its two chief ingredients, coca and kola (with the spelling changed to "cola" to highlight the alliteration; by this time, damiana was no longer an ingredient). The Coca-Cola Company's official historians, anxious to suppress the notion that cocaine was ever a part of their drink, deny that the name is anything but meaningless nonsense syllables. Pemberton's published comments, however, make clear that he considered coca leaf the most vital ingredient in the mixture. The first advertisement for the drink, in the May 29, 1886, *Atlanta Journal*, mentions both the coca leaf and the kola nut. Robinson's June 16, 1887, advertisement in the same paper was the first to use his Spenserian script logo.

Despite the temporary prohibition (it was repealed in November of 1887), Pemberton continued to sell his coca wines: A May 1, 1887, article in the *Atlanta Constitution* reported daily sales of five gross (720 bottles) of Pemberton's French Wine Coca, far more than his Coca-Cola sales (though the comparison is hard to make, since he sold Coca-Cola in syrup form, to be mixed in soda fountains at pharmacies). Realizing that he was near the end of his life, and hoping to leave behind a prosperous company for his son, now in his early thirties, Pemberton quickly prosecuted various schemes, some of them less than scrupulous, to ensure the perpetuation of his invention.

The way in which he secured legal title to his invention was typical of the patent medicine business of the time. "Patent" is a misnomer, for the purpose of a patent is to make every facet of an invention public, whereas makers of patent medicines found more security in keeping their formulas secret. The legal protection they sought was not a patent but a trademark, and Pemberton was granted one for the name Coca-Cola on June 28, 1887. At the same time, he sold the manufacturing equipment, the formula, and two-thirds of the right to the product to soda fountain owner Willis Venable and investor George Lowndes. That October, he placed a blind ad offering half interest in an unnamed business for $2,000. He sold a half interest to three buyers, a clear case of fraud. In March of 1888, Pemberton's dissolute son Charley asserted the right to the product that his father intended by incorporating with three partners the Coca-Cola Company. As the various "owners" of Coca-Cola tried in vain to work out the details, Pemberton died of stomach cancer in August of 1888.

IMPACT

Pemberton could not have dreamed that his invention would become the most recognized corporate name in the world, though he clearly understood that its sales would be nationwide. In fact, he claimed nationwide sales in his own advertising, though his claims may have been exaggerated, and thorough market penetration outside of Atlanta in the scant two years from the launch of Coke in April, 1886, to Pemberton's death in August, 1888, is unlikely. Nevertheless, it is impossible to overstate the cultural impact of Coca-Cola. It is the best-known brand name in the world, and the name itself is second only to "O.K." as the most-known word in the world. It is marketed in more than two hundred countries—more than the number of member states in the United Nations.

With only a few minor changes (and one major one, the "New Coke" fiasco of 1985), the formula for Coca-Cola has remained essentially the same as Pemberton's original. In 1904, the company substituted spent coca leaves—the remainder after the extraction of cocaine—for raw leaves. In 1935, it changed the source of two minor ingredients to allow Coke to be certified kosher. In 1985, the year of the New Coke controversy, much of the soft drink industry switched from cane sugar to high-fructose corn syrup. The New Coke outperformed the original formula in taste tests, but nostalgia for the old drink forced Coca-Cola to bring it back under the name of "Coca-Cola Classic" only months after launching New Coke. For better or for worse, Pemberton's soft drink has become an emblem of America—so much so that America's support of Israel led to an Arab League boycott of Coca-Cola in 1968.

—*John R. Holmes*

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Hays, Constance L. *The Real Thing: Truth and Power at the Coca-Cola Company*. New York: Random House, 2004. While Hays is mostly concerned with Coca-Cola's corporate history, she does touch lightly on Pemberton's invention of the drink near the beginning of the book.

Kahn, Eli J. *The Big Drink*. New York: Random House, 1960. A popular writer for *The New Yorker*, Kahn was one of the first journalists to discover that the story of the invention and marketing of Coca-Cola makes fascinating reading.

Pendergast, Mark. *For God, Country, and Coca-Cola: The Definitive History of the Great American Soft Drink and the Company That Makes It*. 2d ed. New York: Basic Books, 2000. Of all of the books about the Coca-Cola Company, this contains the most information about Pemberton. Pendergast had complete access to Coca-Cola files, yet his work remains independent from the official company historians.

See also: Percy Lavon Julian; Joseph Priestley; Jacob Schick.

JOHN R. PIERCE

American electrical engineer

Pierce invented the Echo and Telstar satellites, the first communication satellites. Other inventions of his include the Pierce electron gun and the klystron oscillator, electronic devices used in linear particle accelerators.

Born: March 27, 1910; Des Moines, Iowa
Died: April 2, 2002; Mountain View, California
Also known as: John Robinson Pierce (full name); J. J. Coupling (pseudonym)
Primary fields: Communications; electronics and electrical engineering
Primary invention: Echo and Telstar satellites

EARLY LIFE

John Robinson Pierce was the son of an owner of a midwestern millinery chain. Pierce's father had no interest in science, but his mother was intensely involved in her son's scientific and inventing interests. Pierce was early interested in Meccano construction sets. He was fascinated by electric motors, which he regarded as "a sort of natural magic," and had his mother read to him about them. He became an avid reader of science and science fiction. Pierce attended high school for the first two years in Mason City, Iowa, then a year in St. Paul, Minnesota, and a final year in Long Beach, California. As a high school senior, he went through a phase of "glider mad-ness"; his mother even flew with him once. Before graduating in 1929, he and two friends won a silver cup at a glider meet in San Diego, California. That year, he published his first book, *How to Build and Fly Gliders*. In 1930, he published his first story in *Science Wonder Stories*.

Pierce attended the California Institute of Technology (Caltech) in Pasadena, where he pursued science, piano, and fiction writing. Initially, he pursued aeronautics but "got tired of rivets," and he turned to chemistry and amateur photography, planning to work for Eastman Kodak. Pierce found that he detested drafting and decided to pursue electrical engineering. After earning his Ph.D. in that discipline in 1936, he secured a job at Bell Telephone Laboratories in Murray Hill, New Jersey.

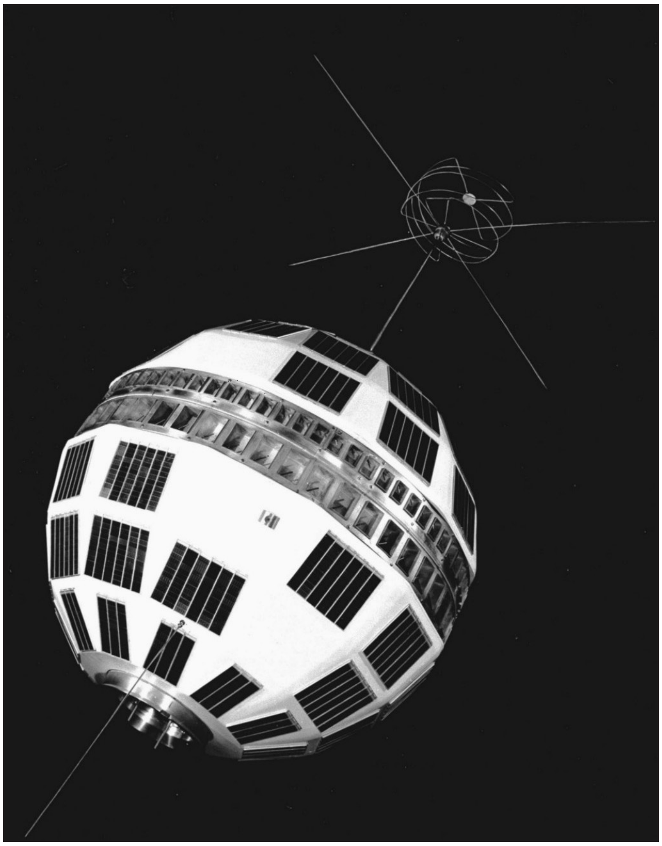
LIFE'S WORK

Pierce worked at Bell Labs from 1936 to 1971. There he would design most of his inventions, eighty-three in all. He was told to work on vacuum tubes despite initially knowing next to nothing about the technology. He soon made numerous inventions in that field and wrote several technical and popular books on it. In 1944, Pierce met Rudolf Kompfner at a British lab and brought him to Bell Labs in 1951. Pierce greatly improved and perfected Kompfner's traveling-wave tube, a specialized vacuum tube that amplifies microwave signals, giving it greater stability and more broadband capability. Pierce coinvented the low-voltage reflex klystron oscillator, used in X-band radar during World War II and later in satellites. Another notable invention of his was the Pierce electron gun, which produces high-density electron beams. He also introduced periodic focusing using permanent magnets, making the vacuum tubes much lighter for satellites and space travel.

In 1948, Claude Elwood Shannon (the creator of information theory), Bernard M. Oliver, and Pierce published a paper on pulse-code modulation (PCM), a technique for converting an analog signal to a digital one. "The Philosophy of PCM" became the manifesto for the eventual transformation of most analog devices into digital ones over the next half century.

In 1952, Pierce proposed the idea of communication satellites in his science-fiction story "Don't Write: Telegraph," written under the pseudonym J. J. Coupling. Pierce was unaware of Arthur C. Clarke's similar idea in a science-fiction story written a decade earlier. Pierce, however, went on to actually develop the technology. He learned of large weather balloons used by the Air Force and immediately thought of using one as a passive satellite communication device. He published a technical article on the topic in 1955 but got little response. The chief executive officer (CEO) of Bell Labs initially opposed the idea, citing fears of accusations of monopoly against Bell. The next CEO supported the project, leading to the launch of the Echo satellite in 1960. Pierce next developed an active satellite, Telstar, which transmitted signals rather than simply reflecting them. Launched in 1962, Telstar broadcast television signals across the Atlantic. A nearly identical satellite, Telstar 2, was launched in 1963.

In 1952, Pierce became director of electronics research at Bell Labs, a position he held until 1962. He served as executive director of the Research-Communications Principles Division from 1965 to 1971. Pierce excelled not only as a theorist and inventor but also as a manager and mentor for many other engineers at the company. He spent much



Launched in 1962, Telstar was the first communication satellite, used to relay telephone and television signals. (AP/Wide World Photos) time visiting labs, asking penetrating questions, and making ingenious suggestions. He was extraordinarily talented at translating technical descriptions of projects and inventions into clear, nontechnical prose that nonspecialists could understand. Sometimes he made the nature of the invention clearer to the inventors themselves. His dozen books of popular science reflect this talent.

Pierce did not tolerate vague statements dressed in technical jargon, nor did he put up with slowness and laziness. He was intellectually impatient and could be intimidating. He was highly critical of some lines of research. For instance, he called the discipline of artificial intelligence "real stupidity" and wrote a critical report on machine language translation that led to government defunding of the field, causing it to languish for decades.

While at Bell Labs, Pierce developed an interest in computer-generated music and psychoacoustics, and he wrote books on music theory and the nature of sound. He supported research in computer music at Bell against opposition by higher executives. After hearing a performance of music by Arnold Schoenberg, Pierce wrote pioneering computer music influenced by Shannon's information theory.

Pierce retired from Bell Labs in 1971 and took professorships at Caltech and the Jet Propulsion Laboratory (JPL), where he continued to invent. In 1983, Pierce retired from Caltech and moved to Stanford as a visiting professor of music. Finding that the computer music project at Stanford was poorly funded, he raised several million dollars to support it and never took a salary at the university. There he did major work on computer music and wrote *The Science of Musical Sound* (1983), on the physics of sound and the theory of computer music.

Echo and Telstar Satellites

John R. Pierce first suggested a communication satellite in a science-fiction article in 1952. In 1955, he wrote an article in a technical journal outlining a plan for the device, leading to the development of the first communication satellite, Echo. Upon learning of the existence of large weather balloons, Pierce realized that a large balloon could reflect electromagnetic waves. He also realized that flat reflectors or mirrors would not be practical, but a hundred-foot-diameter sphere would work. General Mills had been making weather balloons but had never made one this large. The balloon would have to be folded into a compact mass in order to be launched in a rocket and then inflated in outer space. The pressure of the air in the inflated balloon against the vacuum of space would be huge. The first balloon, launched in October, 1959, exploded on inflation. It was made of more than eighty-two patches glued together. For the next attempt, a different adhesive was developed by G. T. Schjeldahl Company, whose founder developed an appropriately strong glue. This time, inflation in outer space was successful. A prerecorded speech by President Dwight D. Eisenhower was broadcast by reflecting it off Echo. Echo was a passive satellite, meaning that it could only reflect, not transmit, signals sent to it.

Pierce next oversaw the development of Telstar, an active satellite capable of transmitting signals. One commercial reason for using an active satellite was that it could handle television bandwidths. American Telephone and Telegraph (AT&T), Bell Labs, the National Aeronautics and Space Administration (NASA), and the British and French national post offices collaborated on the project. Traveling-wave tube transponders (used for signal transmission), developed by Rudolf Kompfner and perfected by Pierce, were used on the satellite. Telstar used solar cells for power. The satellite had a ring of feed horns that precisely directed the outgoing signals. Telstar was launched by NASA on July 10, 1962. Within two weeks, it transmitted its first live TV broadcast, a Major League Baseball game. The broadcast was supposed to have begun with remarks by President John F. Kennedy, but the signal was received before Kennedy spoke. Telstar subsequently had about four hundred transmission sessions of TV, telephone, and telegraph signals.

Unfortunately, the United States had tested a high-altitude nuclear bomb the day before Telstar was launched, exciting the Van Allen radiation belt where the satellite went into orbit. The radiation from this detonation, along with that of other Soviet and U.S. tests, eventually ruined the satellite's transistors, and Telstar 1 went dead five months after it was launched. It was restarted but failed for other reasons two months later. Many subsequent, more complex active satellites were named Telstars.

Pierce was as much a writer as an engineer and inventor. He published several science-fiction stories in *Astounding Science Fiction, Penthouse*, and other magazines during his career. Later in life, Pierce contracted Parkinson's disease and moved to an assisted-living home. He died in 2002 at the age of ninety-two, survived by his third wife and two children by his first wife.

Impact

Pierce's work has influenced the fields of telecommunications, physics, digital technology, and music. His invention of the communication satellites made worldwide television broadcasting possible and eventually led to inexpensive long-distance telephone communication. The Telstar satellite made such an immediate social impact that various musicians wrote songs named for it. Pierce's klystrons are used in radar systems and in linear particle accelerators, such as the Stanford Linear Accelerator (SLAC). The PCM paper he coauthored inspired the decades-long development of digital systems, namely digital computers. In the field of music, Pierce codiscovered the Bohlen-Pierce musical scale, in which the octave triples rather than doubles the frequency of the original tone. The scale has been used by a handful of major computer musicians.

—*Val Dusek*

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Whiting, Jim. *John R. Pierce: Pioneer in Satellite Communications*. Hockessin, Del.: Mitchell Lane: 2004. Excellent account of the life of Pierce, with an emphasis on his work on communication satellites, including background on the development of rocketry: for teenagers. Photographs, time lines, and bibliography.

See also: Ernst Alexanderson; Edwin H. Armstrong; John Bardeen; Willard S. Boyle; Walter H. Brattain; Lee De Forest; Ivan A. Getting; Jack St. Clair Kilby; Claude Elwood Shannon; William Shockley.

ROY J. PLUNKETT

American chemist

Plunkett is best known for his accidental discovery of Teflon while researching chlorofluorocarbon refrigerants. Teflon's nonstick and nonreactive properties made it an ideal material for many military, commercial, and medical applications and helped transform the plastics industry.

Born: June 26, 1910; New Carlisle, Ohio
Died: May 12, 1994; Corpus Christi, Texas
Primary field: Chemistry
Primary invention: Teflon

EARLY LIFE

Roy J. Plunkett was born in New Carlisle, Ohio, and spent his childhood on his parents' farm. He attended Manchester College in Indiana, where one of his roommates was Paul J. Flory, who later won the 1984 Nobel Prize in Chemistry for his contributions to polymer theory, the area in which Plunkett would make his greatest scientific contributions. Plunkett graduated with a B.A. in chemistry in 1932. He earned his master's degree and Ph.D. in chemistry from Ohio State University in 1933 and 1936, respectively. He would also receive honorary doctorate degrees from Manchester College, Washington College, and Ohio State University. After college, he married his wife, Lois, and had two sons, Michael and Patrick. Plunkett found his first job at E. I. du Pont de Nemours and Company (DuPont), the company with which he would spend his entire career. He was hired in 1936 as a research chemist at DuPont's Jackson Laboratory in Deepwater, New Jersey. His first assignment involved research into chlorofluorocarbon (CFC) refrigerants.

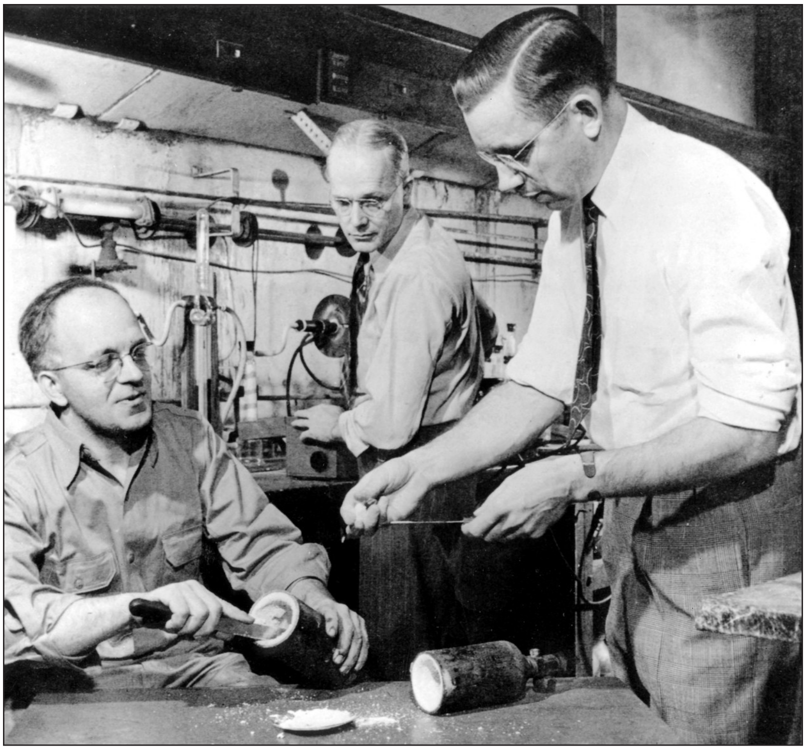
LIFE'S WORK

Plunkett was assigned to a joint research effort between DuPont and General Motors' Frigidaire Division to develop the chemistry of fluorocarbons. The project sought to replace the commonly used sulfur dioxide and ammonia for refrigerators and air conditioners with fluids that were nontoxic, nonflammable, odorless, and colorless. Plunkett was to research the coolant tetrafluoroethylene (TFE), a gas normally stored in small cylinders at room temperature. It was during an experiment on this project that Plunkett would accidentally discover what became his best-known invention, which would revolutionize the field of polymer research.

In 1938, the twenty-seven-year-old Plunkett opened the valve of one of his cylinders in order to retrieve the TFE stored inside, which had been chilled to a dry-ice temperature of –110° Fahrenheit (–76° Celsius). When no gas emerged, Plunkett at first believed that it had somehow leaked from the storage cylinder. After weighing the cylinder, however, Plunkett realized that the unchanged weight meant that the gas was somehow still inside. Also, further investigation revealed that the cylinder's valve was not clogged. Plunkett next cut the storage cylinder in half, revealing a white, waxy solid substance coating the inside. Plunkett had accidentally created polytetrafluoroethylene (PTFE), a fluorocarbon polymer formed when gas molecules join together in a chainlike reaction.

Plunkett received a patent for his invention in 1941. Although his discovery of PTFE was the accidental result of a failed experiment, he had the knowledge and intuition to realize that the substance had several physical properties that could make it useful and that it should be investigated. In particular, he noted its chemical inertness and slippery quality. DuPont's Central Research Division performed numerous experiments on PTFE over the next decade, testing its ability to withstand strong acids and bases, powerful chemicals and solvents, and extreme hot and cold temperatures. Despite its beneficial properties, PTFE at first proved too expensive to produce to make it commercially viable, but DuPont was able to introduce it to the commercial market under the brand name Teflon by the end of the decade.

While DuPont developed Teflon for commercial use, Plunkett continued to build his distinguished career with the company in other divisions. In 1939, Plunkett was promoted to chief chemist for the manufacture of tetraethyl lead at DuPont's largest plant, a role that he would fill until 1952. Tetraethyl lead was an important additive that raised octane levels when added to gasoline. After that, he served as DuPont's director of operations in the Freon Products Division in Wilmington, Delaware. Plunkett received numerous awards and other forms of recognition in his lifetime, including the Philadelphia Scott Medal in 1960, and induction into the Plastics Hall of Fame in 1973 and the Inventors Hall of Fame in 1985. He retired from DuPont in 1975 and died of cancer in Corpus Christi, Texas, on May 12, 1994, at the age of eighty-three.



Roy J. Plunkett, right, takes part in a reenactment of the discovery of Teflon. (Hagley Museum and Library)

TEFLON

Polytetrafluoroethylene (PTFE), commonly known by the DuPont trade name Teflon, is a synthetic fluoropolymer with a high molecular weight consisting of carbon and fluorine. At room temperature, it is a white, waxy, dull, plastic-like solid. Teflon is valued for its slipperiness and chemical inertness and can be used in different forms, such as a solid, a lubricant, or a powder. Even before it became commercially viable, Teflon made its first significant contribution in the field of military weapons production. One of its first uses involved the top-secret Manhattan Project, which developed the first atomic bomb during World War II. Teflon was used on gaskets within the bomb to seal pumps and piping because it would not corrode when it came in contact with the bomb's corrosive chemical elements.

Since this early use, Teflon has proven valuable in a number of other military and governmental applications. It continues to be used in the production of explosive devices and power reactors in places such as uranium-enrichment plants because of its nonreactive properties. Teflon-coated fibers have been used in the production of the pressurized space suits used by astronauts since the U.S. Apollo program designed to land a man on the Moon in the 1960's. Teflon prevented chafing and acted as a flame retardant. The space industry also uses Teflon to insulate spacecraft wires and cables and satellite components as well as to make nose cones and heat shields that protect spacecraft during launch and reentry into Earth's atmosphere.

Teflon has proven equally versatile in the private commercial and medical sectors. One of its earliest and best-known commercial uses was as a durable coating for frying pans and other cookware and utensils. Teflon's nontoxic and slippery qualities allow for easy cleaning. Teflon's flexibility and the fact that it does not produce harmful reactions in the human body make it an ideal material for myriad medical uses, including its use in implanted devices such as heart valves, pacemakers, bone and tendon substitutes, and artificial corneas as well as nonimplanted products such as dentures and body piercings. It is used in clothing manufacture and materials such as Gore-Tex because of its ability to protect garments from moisture damage, dirt, and other stains.

As a lubricant in machinery, Teflon reduces friction, preserving energy and preventing excessive wear and tear on machine parts. It has been used in electric wires, cables, and connector assemblies, microchip packaging, circuit boards, pyrotechnic compositions, infrared decoy flares, solid-fuel rocket propellant igniters, armor-piercing bullets, computer mice feet, plumbing, and thread seal tape. It is used to make containers for reactive and corrosive chemicals and has proved valuable to the field of optical radiometry. Teflon has even been shown to prevent insects from climbing up surfaces painted with it. One of its newer applications is its use in building materials. For example, Teflon was used in construction of the roof of the Hubert H. Humphrey Metrodome in Minneapolis, Minnesota, and the Millennium Dome in London.

IMPACT

Plunkett is remembered as a pioneer in the fields of polymer chemistry and materials science. His determination to study the result of a failed experiment became an often-cited example of the importance of recognizing the role of luck and an open mind in the process of scientific discovery. His work in fluoropolymers played a critical early role in the development of what became a multibillion-dollar plastics industry. Teflon's military applications, beginning with its use in production of the first atomic bombs, aided national defense. Teflon became so well known that it became a national catchphrase by the 1980's, when President Ronald Reagan became known as the "Teflon President" because the scandals that plagued his administration did not seem to "stick" to him personally and affect his popularity.

In addition to Plunkett's discovery of the polymer Teflon, his research and development contributions during his DuPont career have resulted in new products and processes utilized in the refrigeration, aerosol, electronics, plastics, and aerospace industries. Other useful polymers developed based on Plunkett's accidental discovery include neoprene and nylon. Plunkett's name also lives on through DuPont's Plunkett Awards, given each year in recognition of groundbreaking innovations using DuPont fluoropolymer products.

—*Marcella Bush Trevino*

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See also: Leo Hendrik Baekeland; Jacques Edwin Brandenberger; Wallace Hume Carothers; Charles Goodyear; Stephanie Kwolek; Patsy O'Connell Sherman; Earl S. Tupper; Otto Wichterle.

JOSEPH PRIESTLEY

English theologian and scientist

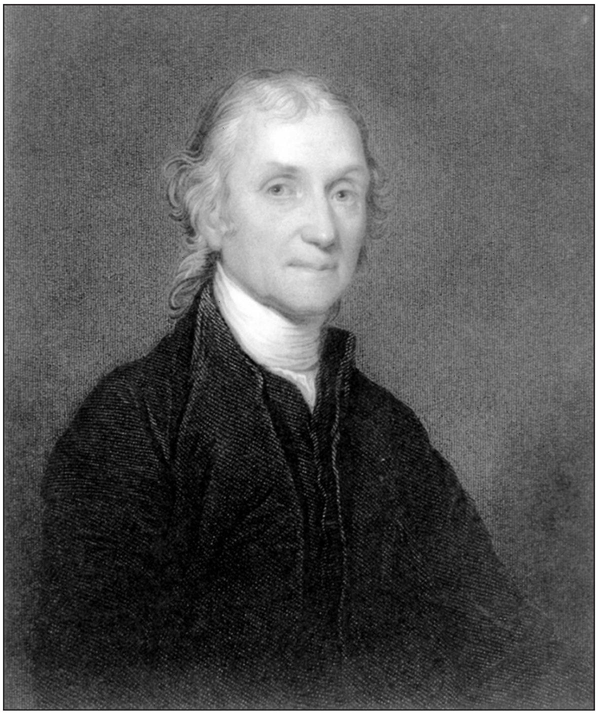
Although most famous for his discovery of oxygen, Priestley developed apparatuses for discovering other new gases. He also dissolved carbon dioxide in water, thereby creating soda water, and he found the first eraser, which he called a "rubber."

Born: March 13, 1733; Birstall Fieldhead, Yorkshire (now West Yorkshire), England
Died: February 6, 1804; Northumberland, Pennsylvania
Primary fields: Chemistry; physics
Primary inventions: Soda water; apparatuses for discovering gases; the eraser

EARLY LIFE

Joseph Priestley was born in Birstall Fieldhead in the north central English county of Yorkshire. His father, Jonas, was a weaver and finisher of woolen cloth, and his mother, Mary, was the daughter of a farmer. After his mother died in 1739, his father asked his sister Sarah and her husband, John Keighley, to raise Joseph, which they did, sending him to Batley Grammar School, where he mastered Latin and began learning Greek. Sarah Keighley's interest in Nonconformist religions influenced Joseph, particularly after a bout with consumption interrupted his education. Through self-study and the help of a tutor, he learned several modern languages, including French, Italian, and German, as well as the rudiments of mathematics. Although his illness left him with a stutter, he was determined to become a minister, and in 1752 he traveled south to Daventry, near Northampton, where he entered a Dissenting academy. After studying the Bible and reading such books as David Hartley's *Observations on Man, His Frame, His Duty, and His Expectations* (1749), Priestley changed his religious views from Calvinism through Arminianism to Arianism. He embarked on a lifelong quest to create a Christian philosophy in which religion and science were compatible.

When, in 1755, Priestley left Daventry to become an assistant minister to a small congregation at Needham Market in Suffolk, he had already acquired a deep knowledge of theology, history, and natural philosophy, and he



Joseph Priestley. (Library of Congress)

had begun to write his *Institutes of Natural and Revealed Religion* (1772-1774). However, his heterodox views and stammering speech made him a controversial and ineffective preacher. In 1758, he moved north to a ministry at Nantwich, near Manchester, in Cheshire. He opened a school where, in addition to languages and history, he taught natural philosophy, and he was even able to purchase scientific instruments and perform experiments. In 1761, he moved to Warrington, where he taught modern languages at the town's Dissenting academy, and where, in 1762, he married Mary Wilkinson, whom he had met at Nantwich and who proved to be an intelligent and supportive wife. He also found time to publish works on history, biography, and education, which led to his being awarded a doctor of laws degree from Edinburgh University in 1764, and thereafter he was known as "Dr. Priestley."

LIFE'S WORK

During his remaining years at Warrington, Priestley continued to write about the history of Christianity, but he also became interested in the history of science. He interpreted both histories as reflecting God's plan for the perfection of humanity. He met Benjamin Franklin in London during the winter of 1765-1766. Franklin, who had already invented the lightning rod, encouraged Priestley to complete his book on electricity. *The History and Present State of Electricity with Original Experiments*, first published in 1767, not only included Priestley's analysis of the experiments, discoveries, and inventions of others but also discussed some of his own experiments—for example, his discovery that charcoal conducted electricity.

The most important period for Priestley's contributions to science and invention began in 1767, when he moved from Warrington to Leeds. Here he became minister at Mill Hill Chapel and made two of his most important discoveries. The first was carbonated water, which was the result of his experiments at a brewery. The second occurred when, in 1770, he was working on a popularization of his history of electricity. He discovered that the hardened sap from certain trees in Brazil and India was able to rub out lead pencil marks. He published his observations on what he called a "rubber."

Priestley's experiments with "mephitic air" had begun while he was writing his history of electricity, and he had discovered that this gas (today's carbon dioxide) was a nonconductor. Joseph Black had done extensive work on this gas, which he called "fixed air," and Priestley, whose interest in chemistry had been piqued by a series of chemical lectures he had attended while at Warrington Academy, decided to turn his attention to chemistry. He studied Stephen Hales's *Vegetable Staticks* (1727) and adapted his techniques for the generation, collection, and manipulation of gases. The first new gas that Priestley discovered was "nitrous air" (today's nitric oxide). Although Hales had actually formed this gas, he did not investigate its properties, whereas Priestley subjected this gas to extensive physical and chemical analysis. He also invented a new technique for collecting those gases that dissolved in water. He used mercury instead of water and in this way discovered "acid air," later called "marine acid air" (today's hydrogen chloride).

His investigations of gases were facilitated when, in 1773, Lord Shelburne invited him to become librarian at his estate in Wiltshire. Here and at Lord Shelburne's town house in London, Priestley had sufficient leisure to conduct an important series of experiments in which he discovered several new gases. His most famous discovery was made when, using a powerful lens, he focused sunlight on a red compound of mercury, thereby generating a gas that had unusual properties. Compared to common air, a candle flame burned longer and brighter and a mouse lived longer in it. Because he was an ardent advocate of the phlogiston theory (which held that combustible substances contained a weightless fluid called phlogiston), he named his new gas “dephlogisticated air.” He had, in fact, discovered oxygen. Using his new techniques, he was able to discover other important gases, such as “dephlogisticated nitrous air” (today’s nitrous oxide, or laughing gas), “alkaline air” (today’s ammonia), “vitriolic acid air” (today’s sulfur dioxide), and “fluor acid air” (today’s silicon tetrafluoride). He was also able to deepen his understanding of plant respiration when, in modern terms, he found that plants absorb carbon dioxide from the atmosphere and release oxygen. He gradually published his *Experiments and Observations on Different Kinds of Air* in several volumes between 1774 and 1786.

Priestley and Lord Shelburne amicably parted in 1780, when Priestley became a minister at the New Meeting House in Birmingham. He settled his family, which now included three sons and a daughter, at Fairhill, and he became a member of an intellectual family through the Lunar Society, whose members included Erasmus Darwin, James Watt, and Matthew Boulton. They met on Mondays nearest the full moon to discuss scientific discoveries, inventions, and modern industry. Priestley, who had often expressed his sympathies for the American and French Revolutions, found that he was persona non grata for many commoners as well as magistrates, and his home was attacked on July 14, 1791, Bastille Day, with the tacit approval of officials. Although his books, papers, scientific apparatuses, and furniture were destroyed, he and his family managed to escape, eventually settling at Hackney, near London, where he taught for a while. The growing animus against him, however, extended even to members of the Royal Society, and he immigrated to the United States. He and his family created a home in Northumberland, Pennsylvania. He continued to defend his phlogistonist views and befriended such American radicals as John Adams and Thomas Jefferson. He refused to become an American citizen, preferring to live and die as an Englishman, which he did in 1804. He was buried in a Quaker cemetery.

IMPACT

Priestley approached the study of nature as an amateur. His vocation was to serve God and His people as a minister, but his avocation was to explore God’s world through his observations and experiments in physics and chemistry. For him, science and religion were not in conflict,

SODA WATER

Like so much else in Joseph Priestley’s life, his discovery of soda water was serendipitous (he might say providential). When he first moved to Leeds in 1767, he happened to live next door to a brewery, and he became curious about the “mephitic air” that existed above fermenting fluids in the vats. He received permission to do experiments with this gas. For example, he found that this “air” snuffed out a candle flame, and it flowed down the side of the vat, because, as he discovered, it was heavier than common air. He then suspended containers of water above the vat, and he found that the water absorbed the gas, giving it a pleasant taste that reminded him of the mineral waters that had become so popular. He gave this carbonated water to some of his friends, who were as impressed as he was with its invigorating taste. However, in the summer of 1768 he moved away from the brewery to a house on Basinghall Street, and he made no more of what he began calling his “artificial Pyrmont water” (after a famous natural mineral water).

In the spring of 1772, an accidental occurrence while Priestley was dining with the duke of Northumberland stimulated him to return to his earlier discovery. The duke gave Priestley some distilled water that had been produced for the sailors of the Royal Navy. Priestley found it bland, and he told the duke that his carbonated water not only tasted better but also might combat the scurvy that was then decimating British crews on long voyages. Priestley returned to his laboratory and devised a new way of making soda water. By this time, he knew that his mephitic air was the same as the “fixed air” that Joseph Black had been the first to discover. He made a generator for fixed air by reacting “oil of vitriol” (today’s sulfuric acid) with powdered chalk (today’s calcium carbonate) in a container. He was able to transmit the gas created in the container via a tube into a bladder, on which he could exert pressure to force its fixed air into a container of water. In 1772, he published his discovery of soda water and the apparatus to make it in a pamphlet: “Directions for Impregnating Water with Fixed Air in order to communicate to it the peculiar Spirit and Virtues of Pyrmont Water and other Mineral Waters of a Similar Nature.” He made no attempt to patent his discovery or method, and he saw as his reward the happiness that his invention brought to people. Unfortunately, soda water did nothing to cure scurvy, but it did become a successful industry. For example, Jacob Schweppe made his fortune based on it. Others added sugar and flavorings to create a variety of soda drinks. In fact, many have called Priestley “the father of the modern soft-drink industry.”

since knowledge of the natural world would make people more content, loving, and prosperous. Although he insisted that his experiments were only his hobby, their results helped to create new sciences and industries, which would have pleased him, because, like his friend Benjamin Franklin, he felt that new knowledge should lead to practical consequences.

The new gases that Priestley discovered, more than any other scientist in history, helped to create the modern science of chemistry. Furthermore, several of his new gases turned out to have many uses in science, industry, and medicine. For example, oxygen has been used in the steel industry to make steel in oxygen furnaces, and the oxygen-acetylene torch is used in the welding of steel. Oxygen is widely used in many modern rockets. In medicine, oxygen has been found helpful in treating pneumonia, emphysema, and other diseases.

Like Franklin, Priestley refused to patent his discoveries and inventions. This gave entrepreneurs a free hand to develop such discoveries as soda water into profitable products. Priestley also had a lasting influence through his many books. For example, he helped shape the history of science through his books on electricity, optics, and pneumatic chemistry. His writings on history, biography, Christianity, human rights, and representative democracy influenced such pivotal thinkers as Jeremy Bentham and Thomas Jefferson, and his scientific writings influenced such significant figures as Antoine Lavoisier and Charles Darwin. Some scholars choose to separate Priestley's science from his theology and politics, but Priestley himself believed in their unity. This vision energized him to create one of the eighteenth century's most illuminating and influential bodies of work.

—*Robert J. Paradowski*

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See also: Sir Humphry Davy; Benjamin Franklin; Charles Goodyear; Thomas Jefferson; Joseph-Michel and Jacques-Étienne Montgolfier; Alessandro Volta.

PTOLEMY

Egyptian astronomer and mathematician

Ptolemy is most famous for the Ptolemaic astronomical system, which was the culmination of ancient Greek astronomy and the accepted explanation of the cosmos for fourteen hundred years. Ptolemy also published a major treatise on geography and a lesser-known one on optics.

Born: c. 100 C.E.; Possibly Ptolemais Hermii, Egypt
Died: c. 178 C.E.; Possibly Alexandria, Egypt
Also known as: Claudius Ptolemaeus (birth name)
Primary fields: Astronomy; geography
Primary invention: Ptolemaic astronomy

EARLY LIFE

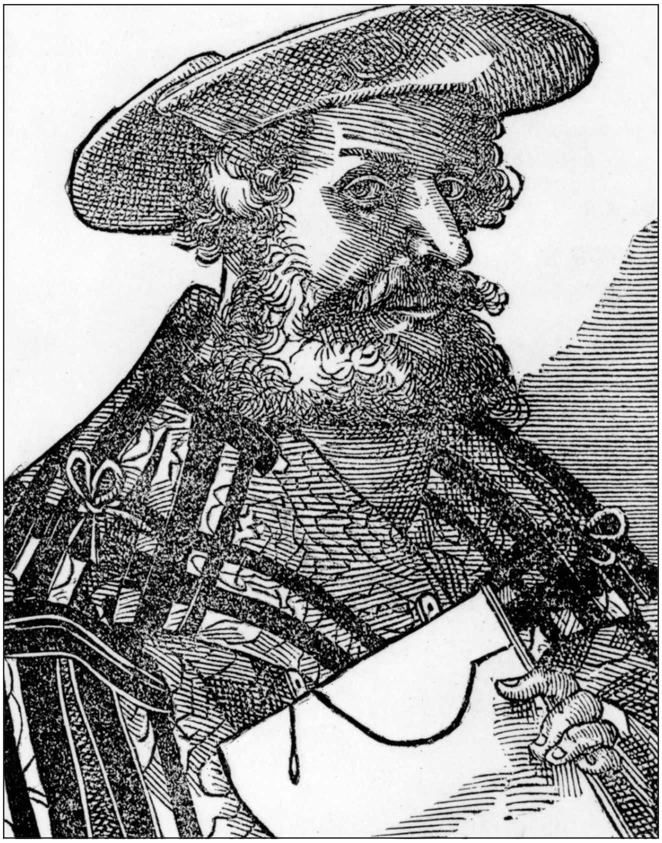
Very little is known of the life of Ptolemy (TOL-uh-mee). The dates of his birth and death are unknown and must be estimated from the dates of his known works. The earliest astronomical observation Ptolemy made and recorded was in the year 127 C.E. The latest was in the year 150. He did enough work after his major astronomical writing to suggest that he might have lived a couple decades after that. Estimates of his birth year range from roughly 85 to 100. He lived to at least the year 150 and possibly to about 178.

Ptolemy apparently lived his entire life in Alexandria, site of the great ancient library, in Egypt. He recorded the location of his observations as Alexandria. However, he may have been born in Ptolemais Hermii, Egypt, rather than Alexandria. Though Ptolemy lived in Egypt, his name suggests that he was of Greek rather than Egyptian descent. The Claudius portion of his full name, Claudius Ptolemaeus, suggests Roman citizenship. One of the Roman emperors probably honored one of Ptolemy's ancestors with Roman citizenship.

LIFE'S WORK

Ptolemy's major contribution to the world's knowledge was in the field of astronomy. Building on the work of earlier Greek astronomers, notably Hipparchus, Ptolemy's book, the *Almagest* (c. 150), was the culmination of ancient Greek astronomy. In the *Almagest*'s thirteen books, Ptolemy works out his geocentric theory of the cosmos, which is now known as the Ptolemaic system. Ptolemy describes mathematically the motions of the then known heavenly bodies. Some of the *Almagest* uses Hipparchus's explanations of motions of heavenly bodies; however, Ptolemy added original ideas of his own.

Rather than jumping directly into Ptolemy's original contributions, the first two books of the *Almagest* provide an introduction to the basic observed motions of heavenly bodies and postulates of ancient Greek astronomy. Ptolemy postulated that Earth and the heavens were spherical and that all motions in the heavens were uniform circular motion. Book 3, on the Sun's motion and the length of the year, as well as book 6, on eclipses, add nothing to the earlier work of Hipparchus. Books 7 and 8 contain a catalog of 1,028 stars. Ptolemy's catalog was based on Hipparchus's observations corrected for precession (the 26,000-year wobble as Earth spins on its axis) to the epoch 137 C.E. Ptolemy apparently added no new observations. In book 5, Ptolemy discusses the astrolabe, used for measuring positions of heavenly bodies,



Ptolemy. (Library of Congress)

and uses observations of the Moon's parallax to deduce the ratio of the distances to the Sun and Moon. Ptolemy based these portions of the *Almagest* largely on Hipparchus's previous work, adding only minor new contributions.

Ptolemy's greatest original contributions are in his theories of the motions of the Moon, in book 4, and the five then known planets, in books 9 through 13. Hipparchus based his theory of the Moon's motion only on observations made during eclipses. By observing the Moon at other times, Ptolemy discovered new motions. Ptolemy's modified theory of the Moon's motions more accurately predicted the Moon's positions.

Ptolemy's greatest achievement, however, was his theory of planetary motions. Ptolemy made additional observations of planetary positions to add to Hipparchus's previous observations. Ptolemy also added two geometric devices to the two geometric devices invented by Hipparchus to predict planetary positions more accurately. Hipparchus used the deferent and epicycle to explain planetary motions. For greater accuracy, Ptolemy added the eccentric and equant point. Using these four geometric devices, he constructed a theory of planetary motion that predicted planetary positions to the accuracy of the observations available until Tycho Brahe made his observations in the sixteenth century. It is likely that Ptolemy considered his system of spheres to be a mathematical tool for calculating planetary positions rather than a physical reality.

Although most famous for his work in astronomy, Ptolemy did significant work in geography. Like his astronomy, Ptolemy's geography builds on previous work but adds his own original contribution. His geography builds on the foundation previously laid by Eratosthenes

Ptolemy's Geocentric System

Ptolemy's geocentric system of the cosmos used four geometric devices to explain observed motions of the planets. Two, the deferent and epicycle, were invented by Hipparchus and used by Ptolemy. The other two, the eccentric and equant, were invented by Ptolemy. One of the fundamental assumptions of ancient Greek astronomy was that heavenly bodies can only move in uniform circles. Hence, Ptolemy had to use combinations of circles to explain the observed planetary motions.

The Sun, Moon, and planets all appear to rise in the east, move across the sky, and set in the west. It is now known that Earth's daily rotation causes this motion. However, in the Greek geocentric system, Earth was stationary. Hipparchus and Ptolemy explained this basic daily motion with a circle called the deferent. The Sun, Moon, and each planet had its own individual deferent that circled the Earth to produce the observed daily cycles.

According to Ptolemy's system, the planets occasionally exhibit periods of retrograde motion, when they appear, for a few weeks, to reverse the direction of their motions as seen against the background of the fixed stars. It is now known that retrograde motion is an illusion caused by an inner planet overtaking an outer planet as they both orbit the Sun. However, Hipparchus, and later Ptolemy, used epicycles to explain retrograde motion. They both required uniform circular motion, so the epicycle was a small circle centered on the deferent. The planet moved on the epicycle while the center of the epicycle moved on the deferent. With the combination of the two uniform circular motions, the planet seemed to reverse direction, as seen from Earth, when it was on the inner portion of the epicycle.

The deferent and epicycle taken together explained retrograde motion; however, they did not accurately predict planetary positions. Ptolemy observed that the apparent speed of the planets varied. He invented the eccentric and equant to explain how planets seemed to change speed as seen from Earth.

Aristotle's physics required Earth to be at the center of the universe; however, it did not impose this requirement on the center of a planet's deferent. Ptolemy displaced the center of each planet's deferent a small amount from Earth and called this displaced point the eccentric. The planet's distance from Earth therefore varied. As the planet's epicycle was on the portion of the deferent closer to Earth, it appeared to move faster as seen from Earth.

Ptolemy also added the equant point, which was placed an equal distance from the Earth as the eccentric but in the opposite direction. Aristotle's physics required uniform circular motion; however, Ptolemy said that the uniform motion along the deferent was as seen from the equant point rather than as seen from the center of the deferent. He cheated on the uniform circular motion requirement to make his theory agree with observed positions of the planets.

Ptolemy used these four devices to accurately predict planetary positions. Nicolaus Copernicus, however, objected to the equant point, which eventually led to the downfall of his model.

and Hipparchus. Ptolemy was the first to use the terms "latitude" and "longitude." He did not invent the idea of a grid system for locations on Earth, but he improved the previous system. Modern maps usually have north at the top and east on the right, which is a convention started by Ptolemy. As both a geographer and astronomer, Ptolemy knew the Earth was spherical. He invented a projection for mapping the spherical Earth on a flat surface.

Ptolemy's geography also had some serious errors that resulted from the fact that Earth had not been sufficiently explored at the time. Ptolemy's most significant geographical error was the size of Earth. Eratosthenes had estimated Earth's size very accurately, but Ptolemy rejected this estimate and used the incorrect smaller value of 18,000 miles for Earth's circumference. Ptolemy also overestimated the size of Asia. The combination of these two errors led Christopher Columbus to think that he could travel from Spain to the East Indies by sailing west.

Ptolemy's work in astronomy and geography required the use of considerable mathematics, and he made important contributions to mathematics, most notably in trigonometry. He also applied his mathematical skill to the study of music theory. In addition, he published a four-volume work on astrology called *Tetrabiblos*. (In Ptolemy's time, astrology was considered an acceptable intellectual pursuit.) Ptolemy's lesser-known work on optics also contains original contributions. He experimentally verified the law of reflection and the fact that light is refracted when passing between media. This work is probably less known because it survives only in the form of imperfect translations. Ptolemy most likely completed it near the end of his life.

IMPACT

Ptolemy's geocentric theory of the cosmos, with its ability to accurately predict planetary positions, was the culmination of ancient Greek astronomy. The Ptolemaic system was so good that it was considered by most scholars to be the unchallenged authority on astronomy for fourteen centuries. From the time of Ptolemy to the time of Nicolaus Copernicus, Arab and European scholars preserved the Ptolemaic system. When required by observations, astronomers made minor adjustments to the system, such as adjusting the size or rate of a deferent or epicycle. However, the basic Ptolemaic system was not changed or seriously challenged until Copernicus published his heliocentric theory. The Ptolemaic system endured so long because, despite being incorrect, it was good science. Ptolemy based his astronomical system on the Greek ideas of aesthetics as well as the now defunct Aristotelian physics. Ptolemy's system of spheres also accurately predicted planetary positions.

Ptolemy's geography forms the basis of much modern geography. The terms "latitude" and "longitude" used to specify locations build on Ptolemy's work. Modern cartography uses various projections to map the spherical Earth on flat maps. Ptolemy pioneered this technique. Ptolemy's geographical work was lost to European civilization until the fourteenth century, but it had a profound effect on Western civilization. Ptolemy's knowledge that Earth was spherical, combined with his underestimate of Earth's size and overestimate of Asia's size influenced Columbus. Columbus thought that sailing west to reach the East Indies would be easy. This error, of course, led to the discovery of the New World.

—Paul A. Heckert

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See also: Ctesibius of Alexandria; Al-Khwārizmī; Gerardus Mercator.

GEORGE MORTIMER PULLMAN

American industrialist

Pullman revolutionized railroad car design in nineteenth century America. Founding the Pullman Palace Car Company in 1867, Pullman created luxury sleeping, dining, and parlor cars for railroad travelers. To house his employees, he created the planned industrial town of Pullman, Illinois.

Born: March 3, 1831; Brocton, New York
Died: October 19, 1897; Chicago, Illinois
Primary fields: Manufacturing; railway engineering
Primary invention: *Pioneer* sleeping car

EARLY LIFE

George Mortimer Pullman was born in Brocton, New York, on March 3, 1831, to James Lewis Pullman and Emily Caroline Minton. Pullman's formal education ended after the fourth grade. From 1845 to 1848, he worked in a general store in Westfield, New York, run by his maternal uncle. Pullman's father was a carpenter, and in 1848 the boy joined his father and two older brothers in Albion, New York, where they were working moving buildings along the Erie Canal. In 1853, Pullman's father died, and Pullman took over the business.

In Albion, Pullman became acquainted with Benjamin Field, who from 1854 to 1855 served in the New York State Senate. This acquaintance would lead to an important business partnership. Pullman previously had several very unpleasant experiences traveling by train, and he had come up with some ideas to make long-distance train travel more comfortable. For his part, Field had secured rights to run sleeping cars in the Western states. Soon, Pullman and Field would work together creating sleeping cars.

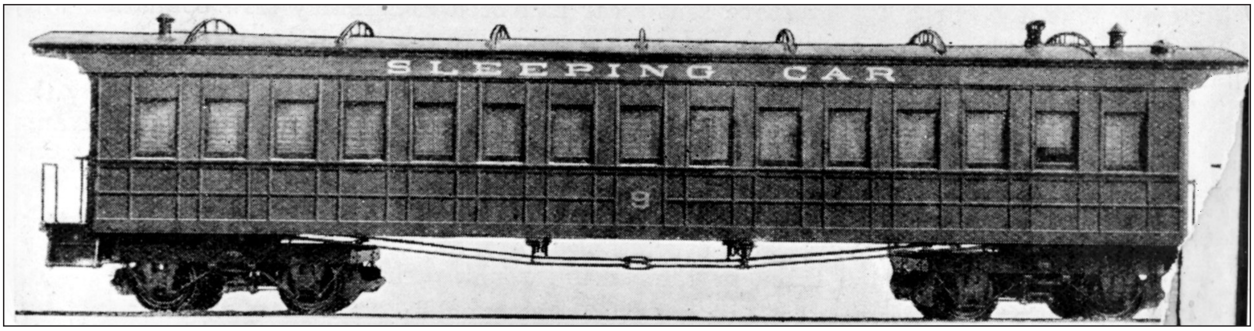
Because of the recession of 1858, Pullman traveled to Chicago, where the city was raising sunken streets, and he found work moving buildings. He was also hired to raise the famous Tremont Hotel. That year, Pullman began working with Field on remodeling two coaches into sleeping cars for the Chicago and Alton Railroad. In 1859, they produced a third sleeping car.

In order to gain capital, Pullman went to the Colorado Territory between 1860 and 1863, where he ran a number of lucrative businesses. While he was in Colorado, Pullman continued revising his designs for railroad sleeping cars. In 1863, he returned to Chicago, and in 1864 Pullman and Field began working on what would be their first Pullman sleeper. Called the *Pioneer*, it rolled into service in 1865. Among the design innovations in this first Pullman sleeper was their patented folding upper berth. At a cost of $20,000, this was the most luxurious sleeping car then in existence, and it set the tone for the creative manufacturing that would be the hallmark of the Pullman cars into the twentieth century.

LIFE'S WORK

Pullman's success was sealed when his *Pioneer* was used in the funeral train for President Abraham Lincoln. Mary Todd Lincoln had seen the *Pioneer* and is said to have personally requested its use for the journey of the funeral train between Chicago and Springfield, Illinois, where the president was buried. As the longest, widest, and highest passenger car on the American railroad, the *Pioneer* required that two feet of clearance be added to all railroad bridges and platforms along the route. The use of the *Pioneer* in Lincoln's funeral train led others to request it for different functions, and soon other railroad lines had to add additional clearance for Pullman's sleeping car.

In 1867, Pullman and Field launched the Pullman Pal-



The Pioneer *sleeping car, introduced in 1865 at a cost of $20,000, set the standard for luxury rail travel.* (Getty Images) ace Car Company. With a capital of $1 million, and 125,000 miles of track upon which they could operate, the company had access to the majority of American railway lines. Pullman advertised personalized service provided by porters, and fresh linen changed daily. Pullman hired African Americans, many of them recently freed slaves, to serve as porters. The Pullman Palace Car Company became the largest employer of African American men in the United States.

As quality food service upon trains was almost nonexistent in 1867, Pullman saw a market for such service. In 1867, Pullman built a "hotel car," the *President*, which was a sleeping car with an attached dining car. Styled a "hotel on wheels," the *President* boasted excellent food and service. In 1868, Pullman built the *Delmonico*, which provided first-class accommodation and food prepared by chefs from Delmonico's Restaurant in New York.

Pullman did not simply market railroad cars for the rich. Rather, they were advertised as "luxury for the middle class." By the mid-1870's, the company had seven hundred Pullman cars operating. Over time, the company created other cars, including parlor cars (1875) and vestibule cars (1887). In the 1890's, the company built "chapel cars," which were railroad cars built as portable churches. By the early 1890's, the Pullman Palace Car Company employed more than 12,000 employees and operated 2,135 cars. Approximately 100,000 persons a night slept on Pullman sleeping cars.

On June 13, 1867, Pullman married Harriett Amelia Sanger, daughter of James Y. Sanger (businessman and railroad builder) and Mary McKibben. They had four children. Pullman built a house in Chicago, and he added homes in Long Branch, New Jersey (where the Pullmans socialized with President Ulysses S. Grant and his family), and Castle Rest on Pullman Island in New York. Pullman also had a home in Albion.

In 1880, Pullman paid $800,000 to purchase four thousand acres west of Lake Calumet, Illinois. There, between 1880 and 1884, he built the planned industrial town of Pullman, Illinois, which cost $8 million to build. Pullman personally planned all aspects of life in the community. He hired architect Solon Beman and landscaper Nathan Barrett to design the town. In addition to railroad car shops for the workers, the town of Pullman had a number of amenities, including a hotel, a stable, a market hall, a bank (the Pullman Savings and Loan), a public park, a library, and a church. The rents for apartments, row houses, and single homes all went to Pullman himself.

The Panic of 1893 hit the railroad industry and the Pullman Palace Car Company in particular. A major cause of the financial panic was overbuilding by American railroads, who borrowed more money than they could repay. In the resulting depression, a number of railroads went bankrupt. Pullman reduced wages by 28 percent while maintaining the rent in the town of Pullman. Pullman

THE *PIONEER*

George Mortimer Pullman's *Pioneer* was, upon its creation in 1865, the most elaborate railroad sleeping car in America. Costing $20,000, the *Pioneer* was built in Chicago at the Chicago and Alton Railroad works. Executives of the Chicago and Alton Railroad had expressed some doubts that the high cost of the *Pioneer* could be recouped. As it was under construction, some called the sleeping car "Pullman's Folly." However, when the car went into service, it quickly gained a reputation for comfort and luxury. Its use in President Abraham Lincoln's funeral train ensured its success. Mary Todd Lincoln herself was said to have observed the *Pioneer*, and she requested its use in her husband's funeral train. Afterward, drawn by the train's presidential connection and its growing reputation for opulence, many famous individuals rode the *Pioneer*, including General Ulysses S. Grant.

The *Pioneer* used Pullman and Benjamin Field's patented folding berth, which folded up into the ceiling of the railroad sleeping car. The car also had lower berths, which were formed from folding down the train seats. Pullman ensured that linen for these upper and lower berths was changed every day, something that was found on no other sleeping car then in existence.

The *Pioneer* had red carpeting, and fine wood paneling throughout added to the elegance of the car. The luxury car was recognized as having the most comfortable seats of any railroad car. The train was lit by coal lamps that were covered with worked silver. The *Pioneer* was higher than other trains in use, and the ventilator transoms near the ceiling added natural lighting while providing air circulation. The car had four state rooms that could be created by means of folding doors.

When it went into service, Pullman's *Pioneer* was the longest (fifty-four feet), widest (ten feet), and highest railroad car then in use. When the *Pioneer* was used on the route for the Lincoln funeral train, clearances at railroad platforms and trestles had to be expanded by two feet to accommodate it. As requests to use the car on other lines increased, clearances were altered accordingly. Thus, Pullman's *Pioneer* made railroad history by setting the standard for railroad design and luxury rail travel.

employees found this to be untenable. Negotiations between the company and representatives of Pullman employees ended with a companywide strike in May, 1894.

By the end of June, the American Railway Union joined the strikers, and 125,000 employees on twenty-nine different railroads refused to handle Pullman cars. Rail transportation was effectively brought to a halt. Pullman did not tolerate union activity, and he responded by requesting assistance from federal troops to break the strike. As the halt in rail transport hindered the delivery of the mail, President Grover Cleveland ordered out twelve thousand soldiers. This led to the destruction of more than $300,000 worth of property, the deaths of thirteen strikers, and the wounding of many more.

After the strike was broken, a federal commission found that Pullman was partly to blame for the strike, by charging excessive rents and thus ensuring that his employees suffered the most from the financial effects of the depression. In 1898, the Pullman Company was forced to cede ownership of the town of Pullman to the city of Chicago. Nonetheless, Pullman's company flourished, and it continued expanding and building newer and better railway cars. Pullman died of a heart attack on October 19, 1897. He was buried in Graceland Cemetery in a coffin covered by concrete and railroad T-rails.

IMPACT

Coming from a humble background and without a full formal education, Pullman rose to become one of America's best-known nineteenth century entrepreneurs. Pullman's resourcefulness helped create an entire industry. His Pullman Palace Car Company set the standard for railroads the world over. Pullman's attention to detail and his marketing genius made the Pullman name the epitome of luxury and comfort.

At his death, Pullman controlled 90 percent of the North American sleeping-car business. His company was worth $63.5 million, and it had a rolling stock of 2,490 railway cars. Pullman's personal estate was valued at $7.6 million. He left $1.2 million to endow an industrial school for the children of Pullman employees (opened 1915).

Upon Pullman's death, Robert Todd Lincoln, son of the late president, became president of the company. Under Lincoln's leadership, the Pullman Company continued to lead the industry in quality railroad cars. Many U.S. presidents and other world leaders traveled in style in Pullman coaches. In 1942, the Pullman Company refitted a car, the *Ferdinand Magellan*, for use by the president of the United States. Presidents Franklin D. Roosevelt, Harry S. Truman, and Dwight D. Eisenhower used the presidential car during their time in office. The *Ferdinand Magellan* was designated as a National Historic Landmark in 1985, the only railroad car to receive such a designation.

While George Mortimer Pullman was a creative entrepreneur who designed the most luxurious railroad cars in the world, his memory was tarnished by his handling of the 1894 Pullman Strike. Pullman's lack of understanding for the plight of his workers during the depression of 1894, and his calling in of federal troops to break the strike, have left a lasting negative imprint on American labor history.

—*J. Francis Watson*

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See also: Andrew Jackson Beard; Peter Cooper; Elijah McCoy; George Stephenson; Richard Trevithick; George Westinghouse.

JACOB RABINOW

American engineer

Rabinow was a prolific inventor with 230 U.S. patents to his credit for inventions ranging from automatic regulating clocks to letter-sorting machines to magnetic computer disk files to safety mechanisms for bombs.

Born: January 8, 1910; Kharkov, Ukraine, Russia (now Kharkiv, Ukraine)
Died: September 11, 1999; Bethesda, Maryland
Also known as: Yakov Aaronovich Rabinovich (birth name)
Primary fields: Computer science; electronics and electrical engineering; military technology and weaponry
Primary inventions: Optical character reader; magnetic disk memory storage; magnetic particle clutch; punch-card sorter; letter sorter

EARLY LIFE

Jacob Rabinow (RA-bih-now) was born in Kharkov, Ukraine, Russia, the son of Aaron and Helen Rabinovich. The Rabinovich family moved to Siberia in 1914, where Aaron ran a shoe factory. There Jacob constructed one of his first inventions, a device for throwing rocks based on a bucksaw that used a stick between two pieces of rope to tighten the blade. An adult saw it and commented on the Roman ballista he had built. It was the first time Jacob had heard of a ballista and also the first time he realized that sometimes people “invent” something they did not know had already been invented.

In 1919, his family moved to China, where his father died. In 1921, when he was eleven years old, his mother brought Jacob and his brother to the United States and settled in Brooklyn, New York. His mother went to work in a corset factory. Jacob attended Thomas Jefferson High School, where he was a member of the mathematics team and the drawing team. His coach, the head of the school’s art department, told him that his drawings were very accurate but lacked spirit and that he should consider being an engineer. Jacob agreed, as that was exactly what he wanted to do, having been inspired by Jules Verne’s stories and watching the workings of his father’s automated shoe factory. He graduated high school in June, 1927, with high marks in his classes.

Lacking the funds to pay for college, Jacob worked at a radio store as a salesman, radio installer, and repairman until the winter of 1928, when he had saved enough money to enter the City College of New York. Told that the engineering field was closed to Jews, he took general studies instead. In 1929, when the Great Depression hit, he decided to study engineering anyway, rationalizing that if he could not get a job, he might as well not be able to get a job in a field that interested him. He also changed his last name from Rabinovich to Rabinow, a spelling that his mother had adopted a few years before.

LIFE’S WORK

Rabinow received a B.S. in electrical engineering in 1933 and an M.A. in electrical engineering in 1934. Willing to take almost any employment, he applied to be a high school science teacher but was rejected because of his Russian accent. In 1935, along with eight hundred other applicants, he took the civil service exams, receiving a 99 in electrical engineering and an 85 in mechanical engineering. While waiting for a job offer, he worked in radio factories.

In 1938, Rabinow applied for a job at the Brooklyn Navy Yard, and they sent him to Washington, D.C., to retrieve his papers from civil service. Civil service said his papers were at the National Bureau of Standards (NBS). When he went there, he was interviewed and hired on the spot to calibrate instruments that measure water flow. He found the instruments old and inaccurate and modified them. He soon earned a reputation as someone who could do original work, which garnered him a position in developing ordnance for war. With World War II on the horizon, the NBS assigned Rabinow the task of developing fuses for bombs. He designed proximity fuses and an acceleration integrator to calculate the velocity of the falling bombs, as well as gyroscopic steering mechanisms for missiles.

In 1946, the U.S. Census Bureau approached the NBS for help in buying a computer to do the upcoming 1950 census. Rabinow consulted on this task, and the Census Bureau purchased a UNIVAC. This project spurred Rabinow to design the first magnetic memory device, consisting of magnetic disks, to store the huge amounts of information generated by computers. He then went on to develop the magnetic particle clutch, which was used in tape recorders and disk drives. A larger version was used in cars. Another of his inventions related to computers was a punch-card sorter.

In 1954, Rabinow left the NBS to start his own company called Rabinow Engineering Co. He had enjoyed

OPTICAL CHARACTER RECOGNITION MACHINES

One of Jacob Rabinow's most significant inventions was the optical character recognition (OCR) machine, which could read both printed and handwritten words and numbers. He was inspired to work on this project in 1938 after discovering that a friend had become blind. Rabinow was curious to see if at least some aspects of human vision could be replicated by a machine.

In 1947, Rabinow was asked by a colleague to modify a U.S. Department of Agriculture machine that the colleague had developed but that did not work. This project led to Rabinow's development of an OCR machine. He made a proposal to his supervisor at the National Bureau of Standards, who agreed to give him the funds for the machine's development. Rabinow's first machine projected each letter of a word from a printed page one by one onto a large disk of photographic paper. There was a Nipkow disk scanner behind the paper and a photocell behind that. The letter on the printed page was compared to each letter on the disk scanner. The more the letter on the scanning disk matched the printed letter, the more light would be blocked to the photocell and the lower the voltage recorded by the cell. After the printed letter had been compared to each letter on the scanning disk, the different recorded voltages would be compared and the "best match" to the printed letter would be determined. This first machine worked, but it was very slow because of all the comparisons that had to be made for each letter. Nevertheless, the "best match" principle employed here would be key for developing more sophisticated machines that could read even handwriting.

Rabinow correctly realized that if standardized printed alphabets and numbers could be developed, they would greatly speed the ability of the OCR machines to read material. Starting in 1956, he spent years on several committees trying to convince them to develop such standardization, but it was slow in coming. Years later, others finally appreciated Rabinow's foresight, and alphabets and numbers were standardized. They are universally used on many media today, such as the bank routing numbers on checks. For the Post Office, where sometimes coding letters and numbers are written over by the person addressing the envelope, Rabinow designed standardized characters that his machines could read independently of overwriting. He streamlined recognition systems to simplify and speed up the reading process. He even incorporated dictionaries into his machines to help the machine decide a correct word by context if it was having difficulty deciphering the word. Today, Rabinow's OCR machines are used extensively throughout business and industry.

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his work at the NBS but was concerned about the political climate at the time and various rumors, such as that the NBS would be taken over by the Army and run as a military laboratory or that it would be split up with various divisions being run by private companies. Sprague Electric offered to pay him $10,000 per year if he would spend half of his time on their projects, an arrangement that provided him with some financial security as he started his own endeavor.

Rabinow handled projects for many companies, including RCA, Remington-Rand, and Airborne Instruments, designing a device to automatically identify railroad freight cars, a machine to count small toy parts as they were packed, a metal statue-carving arm, and an automatic dimmer for car headlights. He even had time to design and receive patents in six countries for an improved continuous ribbon vertical Venetian blind system, because his wife hated the horizontal Venetian blinds in their home, as well as a device for his wife's beautician to use to mix nail polish. Some of his most successful inventions during this time were a self-regulating clock that was eventually used in automotive clocks, a machine that could sort mail that he designed for the U.S. Post Office, and machines that could read typed and handwritten materials through the development of optical character recognition.

By 1972, Rabinow tired of trying to operate his own business, so he sold it to Control Data. He returned to the National Bureau of Standards for a few years, retiring in 1975. His final work while at the NBS was the design of a pickproof lock.

Rabinow continued to act as a consultant to the NBS following his retirement. He began appearing as a guest speaker on college campuses and for professional organizations. He died on September 11, 1999. In 2005, Rabinow was inducted into the National Inventors Hall of Fame.

IMPACT

Rabinow was an ingenious inventor who held 230 patents for items as diverse as the fields that they influenced. Virtually every person in the United States and in many other countries has been affected by one or more of Rabinow's inventions. The safety mechanisms that he invented for bombs undoubtedly protected bombardiers, and his guidance mechanisms helped deliver bombs to their targets during World War II.

His automatic letter-sorting machine mechanized the U.S. Post Office and greatly increased the speed and efficiency of mail delivery. Prior to the adoption of his machine, postal workers had to sort all mail by hand, a tedious and time-consuming process. His magnetic disk memory storage device paved the way for the development of large-scale memory systems for computers. His magnetic particle clutch is still used today in some automobiles, airplanes, and other machinery. For many years, American automobiles came standard with a self-regulating clock that Rabinow had invented.

Rabinow's optical character recognition machines revolutionized business and industry by automating the reading of masses of printed and handwritten material, a process that previously had to be done by hand. The principle of "best match" that he developed for these machines has been a foundation for the development of "thinking" computer programs.

No project was too big to tackle or too small to overlook for Rabinow. Even his little inventions—such as vertical Venetian blinds, folding footstools for shorter people to use at the opera, and a device to mix nail polish—demonstrate his dedication to making the world function better, one invention at a time.

—*Polly D. Steenhagen*

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See also: Otis Boykin; Herman Hollerith; Ray Kurzweil; Don Wetzel.

JESSE RAMSDEN

English designer of scientific tools

Ramsden developed a new way of calibrating measurement instruments, and he applied his method most spectacularly to the construction of large optical instruments, especially astronomical telescopes, of better quality than any that had been made in England before.

Born: October 6, 1735; Salterhebble, near Halifax, Yorkshire, England
Died: November 5, 1800; Brighton, Sussex, England
Primary fields: Astronomy; mechanical engineering
Primary inventions: Dividing engine; theodolite

EARLY LIFE

Jesse Ramsden was the son of Thomas Ramsden, an innkeeper, but little else is known about his family, and information relating to his upbringing is sparse. Between the ages of nine and twelve, he attended the free school in Halifax, and he then went to live with an uncle surnamed Craven somewhere in the North Riding of Yorkshire. While he was there, he studied mathematics with a clergyman surnamed Hall before being apprenticed to a cloth-worker in Halifax.

After completing his apprenticeship in 1755, Ramsden went to London, where he was initially employed as a clerk in a cloth warehouse, but in 1756 he bound himself as an apprentice, for a fee of £12, to Mark Burton, a mathematical instrument maker based on Denmark Street. He soon established a reputation in that occupation for the quality of his work and his assiduity, and he began trading in his own name in the Strand in 1763. He spent a great deal of time at the home of a near neighbor, John Dollond, whose family was famous as makers of optical instruments (its name was still preserved in the early years of the twenty-first century in that of the active firm of British opticians Dollond and Aitchison). On August 10, 1766, Ramsden married John Dollond's daughter Sarah (1743-1796) at St. Martin-in-the-Fields, at the western extremity of the Strand.

As part of his bride's dowry, Ramsden received a share in the patent rights to the achromatic lens, which John Dollond had developed and whose deployment improved astronomical telescopes markedly, although its similar impact on microscopy was delayed for nearly a century because of the difficulty of grinding the smaller lenses required by such instruments. Ramsden immediately opened his own premises as a dealer in optical instruments in the Haymarket. Sarah bore two sons and two daughters between 1767 and 1771, but only one child—John (1768-1841)—survived infancy.

LIFE'S WORK

Ramsden's own expertise as an inventor was mobilized by the desire to bring about improvements to the accuracy of astronomical instruments measuring angles, which were much in demand for mapping the heavens and attempting to determine stellar parallaxes—the key to measuring stellar distances. Although no stellar parallax would be measured until after his death, further pressure of demand was exerted by the Royal Navy's desire to find a means of accurately measuring longitude. Although this quest is often represented as one for better ships' chronometers, it also required minutely accurate sextants. It was a new method of "dividing" sextants—marking up their scales in degrees—that was Ramsden's first triumph as an engineer. He devised a machine—a "dividing engine"—that could lay out such scales mechanically with considerably greater speed and somewhat greater accuracy than a highly skilled craftsman working by hand.

The dividing engine worked on any instrument with a circular scale, including theodolites and octants as well as sextants. The first version became operational in 1767, a second and superior one in 1775. In the meantime, Ramsden moved to larger premises in Piccadilly, although Sarah and his son did not go with him, initially remaining in the Haymarket in a house owned by the Dollonds. The two dwellings were no more than a hundred yards apart, and Ramsden seemingly continued to use his contact with the Dollonds to cultivate useful acquaintances and clients. It is impossible to determine exactly what went wrong with the marriage, but the split was permanent; Sarah was living in Lambeth when she died. A profile of Ramsden published in *The Mirror of Literature, Amusement and Instruction* on July 28, 1827, represented him as living in contented domesticity surrounded by his apprentices, with whom he talked shop all day and all night, but reported that he frequently hummed or sang a popular ballad whose refrain included the couplet "If she is not so true to me/ What care I to whom she be?"

Ramsden's original dividing machine was sold to Jean Baptiste Gaspard Bochart de Saron and smuggled into France (England and France were at war at the time), where it was confiscated during the Revolution and ended up in one of the national collections. It is still on display. The second remained in England, working so successfully that the Commission of Longitude awarded Ramsden a bounty of £300 and bought the rights to the engine for a similar sum, on condition that he provided comprehensive details of its design and construction. He was subsequently able to charge six shillings for graduating sextants for clients. His *Description of an Engine for Dividing Mathematical Instruments* was published in 1777.

THE DIVIDING ENGINE

Jesse Ramsden's second dividing engine—a machine that marks graduations on measurement instruments—had a 45-inch wheel (half as big as that of his first model) incised with 2,160 teeth, which were engaged by a lead screw turned by a treadle, rotated through the desired angle. The body of the device to be divided—usually a sextant—was centered on the wheel. Operated by a semiskilled workman, the machine could divide up the 120° of a sextant's scale in thirty minutes, to a higher degree of accuracy than the most skilled handcraftsman, who would typically require several days to achieve the inferior result.

The importance of the dividing machine was not confined to its greater speed and superior accuracy; because it could graduate sextants of any practical size, to a lower limit of about eight inches in radius, it permitted smaller ones to be used without any loss of accuracy—a vital step forward in the miniaturization of marine instruments. By 1789, Ramsden and his employees had graduated more than a thousand sextants of various sizes, making a relatively inconspicuous but highly significant contribution to the success of British naval vessels in an era of heroic exploration and protracted warfare.

Ramsden then turned his hand to the development of dividing engines for straight line scales, attaining an accuracy of $^1/_{4,000}$ of an inch in 1779. In 1780, he expanded the Piccadilly premises considerably, giving him the space to work on large astronomical instruments, and that became his vocation thereafter, although a workforce of sixty men continued to work on smaller instruments in order to sustain his income. It was as well that they did, because he soon acquired a reputation for unpunctuality in executing major commissions, his perfectionism leaving him incapable of delivering a completed instrument until he was satisfied with its accuracy. An oft-quoted anecdote related that he once turned up at Kew Palace, mistakenly claiming to have an appointment with King George III to deliver a telescope; when the king graciously consented to see him, Ramsden allegedly pointed out that, although he had come on the right day, he had unfortunately "mistaken the year."

Ramsden was elected a fellow of the Royal Society on January 12, 1786. He was the first telescope maker to use a fully circular scale for measurement, which could not be divided mechanically and thus posed a severe challenge to his craftsmanship; he rarely completed one in less than 150 days and often took far longer if he hit a snag that required readjustment or—on occasion—a fresh start. His first full-scale astronomical apparatus was delivered to Giuseppe Piazzi in 1789 and was installed at Palermo Observatory, where it played a part in numerous significant observations of the solar system. It is arguable, however, that a more significant instrument of Ramsden's manufacture was a 36-inch theodolite that he designed for General William Roy's project to reevaluate the longitude between Greenwich and Paris, which was the seed of the Ordnance Survey.

Ramsden also experimented with clockwork-driven equatorial telescopes, based on a design he had published in 1774; he remodeled one in the Royal Observatory at Greenwich in 1775, but the best instrument of that kind he built was one constructed for Sir George Shuckburgh in 1793. Following in John Dollond's footsteps, Ramsden produced an achromatic "Ramsden eyepiece" for telescopes that was very widely used; he also produced two new micrometer designs and a wide variety of other instruments, including barometers, levels, precision balances, and pyrometers. In 1795, he received the Royal Society's Copley Medal for "various improvements to philosophical instruments." He corresponded with scientists throughout Europe, and he was granted membership of St. Petersburg Academy in 1794. Several of his apprentices went on to forge successful careers, including Thomas Jones (1775-1852), and his business was taken over after his death by his foreman, Matthew Berge, who continued trading in Piccadilly until his own death in 1819. Ramsden died in Brighton, but his body was brought back for burial in St. James's Piccadilly, in close proximity to his business premises.

IMPACT

Although it was his large instruments that made Ramsden famous—and delays in their delivery that earned him a wry notoriety—he certainly had a greater practical impact in his own day by virtue of his accurate calibration of small instruments, especially naval sextants. The marine chronometers that "solved" the problem of calculating longitudes at sea could not have done so had they not been operated in collaboration with accurate sextants, whose rapid production Ramsden made feasible. His discovery of the dividing machine was unspectacular by comparison with such contemporary innovations as the steam engine, but the sum of its tiny contributions to millions of measurements was nevertheless vast. His large telescopes did assist considerably, though, in making numerous astronomical discoveries, and his work on equatorial telescopes was a foundation on which many subsequent instrument makers built.

—*Brian Stableford*

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See also: John Campbell; John Harrison; Zacharias Janssen.

IRA REMSEN

American chemist

Remsen was a distinguished chemistry teacher and a prolific writer of highly regarded textbooks. He is best known for his discovery, with Constantin Fahlberg, of the artificial sweetener saccharin.

Born: February 10, 1846; New York, New York
Died: March 4, 1927; Carmel, California
Primary field: Chemistry
Primary invention: Saccharin synthesis

EARLY LIFE

Ira Remsen (REHM-suhn), the only child of James Vanderbilt Remsen and Rosanna Remsen (neé Secor) to survive childhood, was born in New York City in 1846. When Ira was eight years old, his mother's health deteriorated and the family moved to a farm in Rockland County. In this rural setting, the boy acquired a lifelong love of the outdoors and a fascination with nature. His mother died just two years later, and he was sent to live with his maternal great-grandparents, James and Elizabeth Demarest. In this home of a scholarly Dutch Reformed pastor and his cultured wife, young Remsen gained a great love for learning, acquired a taste for scripture, and developed a strong sense of honesty. In later years, he recalled his two years with the Demarests as one of the happiest times of his life. While living with them, Remsen attended the local elementary school, but his father wished him to have a richer education, so they returned to New York City.

There Remsen attended public school until, at fourteen, he enrolled at the New York Free Academy, later the College of the City of New York (CCNY). His father wished his son to study medicine, so Remsen left his undergraduate program before completing his degree. He was placed as an assistant to a practicing physician who was also the professor of chemistry at a homeopathic medical school. It was not long before Remsen realized that he needed a much more rigorous program of study to become a skilled medical professional. He convinced his father that he should enroll in Columbia University's College of Physicians and Surgeons.

Though Remsen received his medical degree with honors in 1867, he was not certain about devoting his life and talents to medicine. As a student, he had acquired some chemistry experience, and after a year of what he later called "critical self-appraisal," he decided that chemistry was his passion. He set off to study with the renowned professors in Germany with their great teaching laboratories.

In Munich, Remsen received valuable training under Jacob Volhard, an analytical chemist of great stature, and he was also able to hear some of Justus Liebigs's outstanding lectures. Volhard advised Remsen to move to the University of Göttingen, where Remsen was introduced to Fredrich Wöhler. At Göttingen, Remsen worked under the direction of Rudolf Fittig and was awarded a Ph.D. in 1870. Upon graduation, he went with his mentor to the University of Tübingen as his assistant. There he had the opportunity to read extensively and to become completely immersed in the German system of graduate education. During these years, Remsen developed the major themes that would constitute his later work.

LIFE'S WORK

From his earliest days in Germany, Remsen had a keen interest in the subtle chemistry of the derivatives of benzene, which are referred to as "aromatic compounds" because some of the common members have a sweet odor. Benzene was discovered by English physicist Michael Faraday in 1825. Its molecular formula, C_6H_6, suggests great reactivity, yet the compound exhibits extraordinary stability. Remsen knew from his days at Göttingen that a carbon atom attached to benzene could be fully oxidized without changing the benzene. One of the great theoretical problems of early organic (or carbon) chemistry was to explain this marked stability.

In Germany, Remsen worked on the oxidation of xylenes, which possess a benzene ring, of which two carbon atoms are each bonded to a methyl group (CH_3). Later, at the University of Tübingen, he found that methyl groups attached adjacent to a sulfonic acid group (SO_3H) are protected from oxidation. He also found that chains of two or three carbon atoms are similarly protected. This observation has been referred to as Remsen's law. In addition, Remsen demonstrated that the more complex sulfamide group (SO_2NH_2) also prevents the oxidation of methyl groups. Later, at Johns Hopkins University, he discovered that the oxidizing agent potassium permanganate did allow the adjacent methyl group to be oxidized. In 1879, Remsen suggested to a postdoctoral student, Constantin Fahlberg, that he try this new oxidation method on 2-methylbenzenesulfonamide. This experiment resulted in the most practical invention of Remsen's career—what Fahlberg later named "saccharin," a substance three hundred to five hundred times sweeter than sugar.

These laboratory successes pale in comparison to Remsen's influence on his students. Remsen was one of those rare professors who possessed a genuine talent for impressing on young minds the beauty as well as the principles of science. When he began teaching at Williams College in Massachusetts in 1872, the year he returned from Germany, he was struck by the poor quality of chemistry textbooks in English. His translation of *Wöhler's Outlines of Organic Chemistry* was published in 1873. In 1876, while still at the college, he published the first of a series of exceedingly popular textbooks entitled *The Principles of Theoretical Chemistry*.

The upper-class liberal arts atmosphere at Williams was not consistent with Remsen's view of scientific education. He was delighted to receive the invitation of Daniel Coit Gilman, the founding president of Johns Hopkins University, to become the institution's first professor of chemistry. It was the intention of the university to offer graduate education based on the German model, and Remsen was just the man to implement that goal. He served the university from 1876 until his retirement in 1913. In 1901, Gilman resigned, and the board of trustees selected Remsen as the new president. He often alluded to the sense of loss he felt in giving up his teaching role, and his former students saw his administrative duties as a great loss to teaching and to the scientific community. Nevertheless, he worked diligently to promote the university's mandate and to serve the public interests of Baltimore as well.

One of Remsen's greatest contributions to the advancement of American chemistry was his founding of the *American Chemical Journal* in 1879. He was its only editor until the fiftieth volume in 1915. At that point, the journal merged with the *Journal of the American Chemical Society*, which remains one of the world's most prestigious scientific journals.

The Synthesis of Saccharin

The discovery of saccharin was a happy accident. In 1879 at Johns Hopkins University, Ira Remsen suggested to a postdoctoral student, Constantin Fahlberg, that he try Remsen's new oxidation method on 2-methylbenzenesulfonamide. One evening at dinner, Fahlberg noticed that his bread tasted unaccountably sweet and also noticed the taste on his unwashed hands. He traced the chemical residue to his laboratory and later named the synthetic compound "saccharin" (from *saccharum*, Latin for "sugar"), which was found to be more than three hundred times sweeter than sucrose. In 1880, the professor and student jointly published their findings in the *American Chemical Journal*, which Remsen had founded the previous year.

Remsen neither sought nor received money or acclaim for the discovery. However, Fahlberg recognized at once the tremendous economic possibilities of the sweet, calorie-free substance that contained no sugar. In 1884, he obtained a patent for the manufacture of saccharin and went on to become a very wealthy man. Known for his contempt for the commercialism of discovery, Remsen later called Fahlberg "a scoundrel." He never contested the patent.

Remsen received many honors in his life. In 1903, he served as president of the American Association for the Advancement of Science. From 1907 to 1913, he was president of the National Academy of Sciences. In addition to a number of honorary degrees, Remsen won the gold medal of the Society of Chemical Industry and both the Willard Gibbs (1914) and the Priestley (1923) medals of the American Chemical Society, for which he had served as president in 1902.

Remsen had married Elizabeth Mallory in 1875, and they had two sons, Ira and Charles. After Remsen retired in 1913, he and his wife spent some tranquil years traveling. He died from a cerebral hemorrhage in 1927.

Impact

During his career, Remsen and his graduate students studied a great many chemical reactions, and together they published more than 170 scientific articles. Remsen aimed to elucidate the principles of chemistry rather than to simply produce new compounds or even new reaction pathways. Nevertheless, he is best known for his discovery, with Fahlberg, of the first artificial sweetener, saccharin. Demand in the United States for the synthetic sweetener increased during the sugar shortages of World War I, and the calorie-free substance was a boon to the food and diet industries in later decades. Saccharin is found in low-calorie soft drinks as well as tabletop sweeteners such as Sweet'N Low.

—K. Thomas Finley

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See also: Michael Faraday; Roy J. Plunkett; Max Tishler.

JESSE W. RENO

American engineer

Reno invented moving stairs, the inclined elevator, better known as the escalator. Some escalators he designed were in use through the 1990's, more than fifty years after his death.

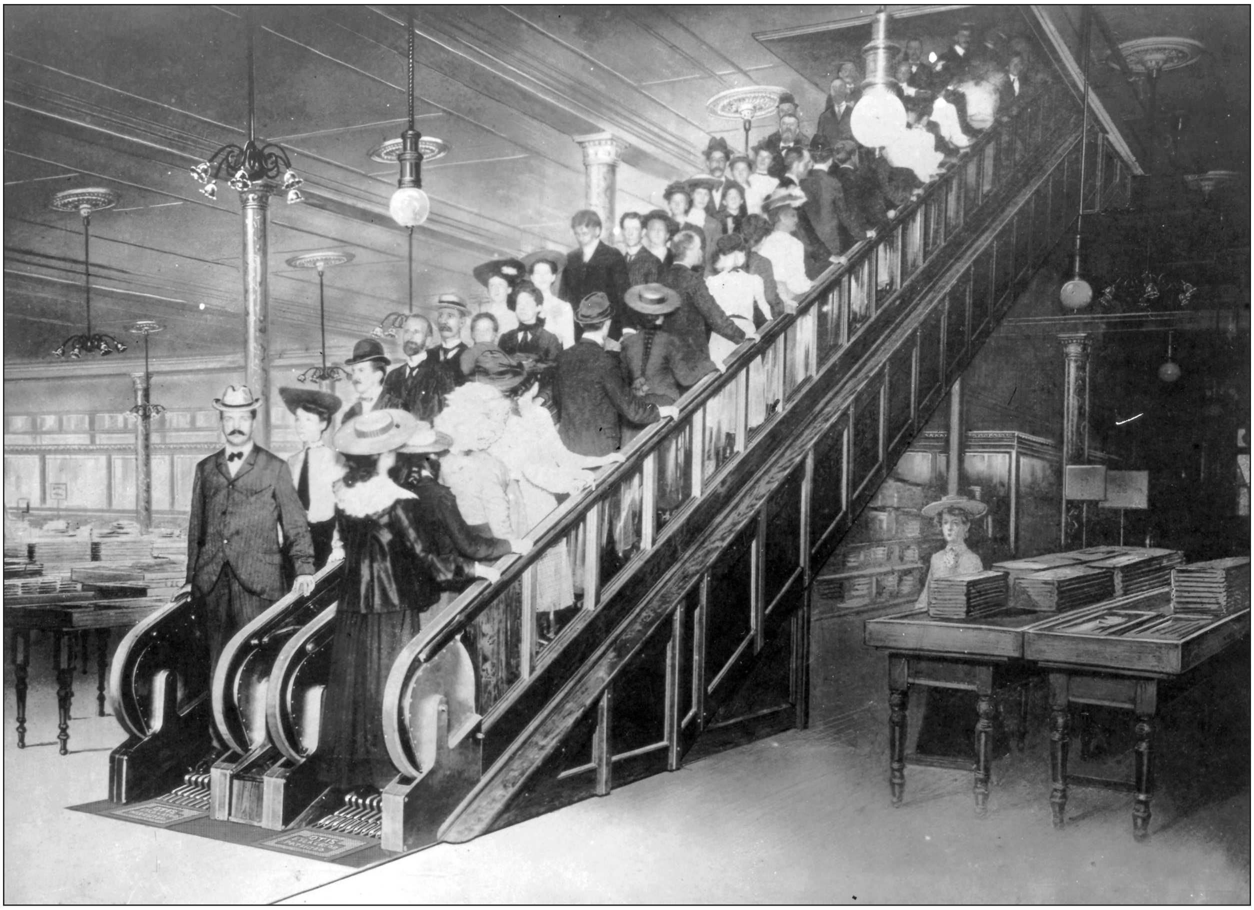
Born: August 4, 1861; Fort Leavenworth, Kansas
Died: June 2, 1947; Pelham Manor, New York
Also known as: Jesse Wilford Reno (full name)
Primary field: Mechanical engineering
Primary invention: Escalator

EARLY LIFE

Mary Bradley Beanes Cross and Jesse Lee Reno wed on November 1, 1853, in Washington D.C. Mary was a well-educated socialite from a prominent D.C. military family. By the time of their wedding, Jesse already had a successful military career, after graduating from the United States Military Academy in 1846. The family was living in Kansas, where Reno was in charge of the Fort Leavenworth arsenal, when their youngest son, Jesse Wilford Reno, was born on August 4, 1861. Jesse Lee was promoted to major general in 1862. He commanded the Ninth Corps during the Second Battle of Bull Run in Virginia on August 28-30, 1862. General Reno was killed in an attack on the evening of September 14 later that year during the Battle of South Mountain in Maryland.

Mary Reno and her children lived in several midwestern and Southern states in the years after the Civil War. During this time, she bought a family burial plot in a Washington, D.C., cemetery, and moved the bodies of her husband and three children who had died there. She was buried with them when she died a few years later.

Jesse W. Reno attended Lehigh University in Pennsylvania, where he majored in engineering. Reno was involved in several activities and organizations there, participating in choir, Chi Phi (Psi chapter), and the fra-



An Otis duplex cleat-type escalator, installed at the R. H. White Company store in Boston, Massachusetts, in 1903. (The Granger Collection, New York)

ternity's lawn tennis club, serving as class historian, and playing on the university's baseball team. He graduated in 1883. Reno worked as an engineer for a mining company in Colorado before moving to Georgia. While working for the Thomson-Houston Electric Company in Americus, Reno built the first electric railway in the southern United States.

LIFE'S WORK

In 1891, after moving to New York City, Reno applied for his first patent. The invention was an idea he had been considering since the age of sixteen: the "new and useful endless conveyor or elevator." The patent went into effect in 1892. Reno built one of the devices and installed it as a ride at Coney Island, New York, in 1896. This early model was more of an inclined bicycle. The ride was inclined 25°, reached a height of seven feet, and moved at a speed of seventy-five feet per minute. Passengers had to be careful when getting on and off the ride to avoid being kicked by fellow riders. Reno's inclined elevator was at Coney Island for two weeks, during which time seventy-five thousand people took rides.

In 1896, Reno submitted a design for a double-decker New York City subway system. Inclined elevators would move passengers from street level to the different underground train platforms. Reno estimated that it would take the city three years to build the system. New York City officials rejected Reno's plan. On January 15, 1901, Reno married the widowed baroness Marie G. Snowman in Kansas. The couple moved to London shortly after the wedding. Reno started the Reno Electric Stairways and Conveyors Company in 1902.

By this time, Reno escalators were being installed in stores throughout the United States and Europe. His early design had been modified into more of an inclined moving walkway. Rails guided a series of wooden pallets on a moving conveyor. Rubber cleats were installed on the wooden stairs to help passengers keep their footing. Early versions of comb plates were located at both ends of the escalator to clean the wooden treads. The machine had two handrails—one stationary, the other cloth-covered rubber that moved at the same speed as the escalator. One drawback of the moving handrail was that the lubrication oil often stained riders' clothing. Reno altered the design so that the inclined elevator was more steplike. The Manhattan Elevated Railroad Company purchased one hundred Reno escalators in 1900. Some of them remained in operation until 1955.

Escalators

Moving stairs, or escalators, are found throughout the world in stores, subway stations, shopping malls, airports, and numerous other places. They are a modern convenience often taken for granted by riders. The first patent for a moving staircase was issued in 1859. Nathan Ames's design was a revolving set of stairs that formed an equilateral triangle. On the left side, passengers would travel up to the point of the triangle, where they would have to exit quickly and avoid passengers attempting to travel down the right side stairs. The belt of stairs would be powered by steam. Ames's machine was never built.

In 1892, two patents were granted for escalator-type machines. The first patent was for Jesse W. Reno's inclined elevator, which he displayed as a ride at Coney Island, New York, in 1896. The second patent was issued to George H. Wheeler for his idea of a moving stairway. Wheeler never developed a prototype, and he sold the patent to Charles Seeberger in 1898. The Otis Elevator Company built and installed the first commercial escalators in 1901. The Seeberger-Otis wooden escalator was installed at the 1900 Paris Exposition, where the public could ride it for a penny. The escalator received the exposition's first prize.

The Otis Elevator Company bought out Seeberger in 1910. In 1911, Otis purchased Reno's company as well. For the next decade, Otis manufactured both Reno's "sloping tread" and Seeberger's "step" models. In the 1920's, David Lindquist and other engineers at Otis combined and improved the two models into the current escalator. Comb plates, placed at the end of escalators, were added around this time. Reno's model had comblike prongs twelve to sixteen inches long. The prongs produced quite a jolt to passengers, who often fell while trying to avoid them. The Seeberger-Otis model had a shunt, or transitional diagonal section, at the ends. Passengers had to sidestep onto the platform while the other foot was still on the moving stairs. The handrails were also redesigned. Reno's model had lubricated handrails to ease friction within the machine, but the lubricant would stain riders' clothing. Instead, Otis engineers switched to nonlubricated, tension-driven rubber handrails coated with canvas. The third change was the standardization of escalator speed, which had ranged from eighty to one hundred feet per minute. The speed was set to ninety feet per minute.

Architects and designers have tried to camouflage escalators for years, hoping to make sure that the machines did not detract from the surrounding environment. However, toward the end of the twentieth century, escalators became design tools. In 1988, the Mitsubishi Electric installed the first "spiral" escalator in the United States, although the San Francisco Center escalator is more of a semicircle than a true spiral like Reno's 1906 model.

Reno then turned his attention to building a spiral escalator. In 1906, he was hired by the London Underground to install one in the Holloway Road train station. He partnered with William Henry Aston, who had developed a flexible pallet and chain system. They built a working model at their own expense for a London subway station. However, passengers never used the spiral walkway because it never passed safety inspections. Ninety years later, it was found in an abandoned tunnel of the station. Reno's spiral escalator is now on display in London's Transport Museum.

In 1903, Reno sold one-third of his business to the Otis Elevator Company. Otis had already begun producing its own version of the inclined elevator based on the patents of Charles Seeberger, who coined the term "escalator" by combining the Latin word *scala* (steps) and "elevator." Seeberger sold his patent rights to the Otis company in 1910, and Reno sold his company to Otis in 1911. Reno's design was sold as the "cleat-type escalator" until 1921, when Otis combined it with Seeberger's model to form the modern escalator.

In 1921, the American Society of Mechanical Engineers created a voluntary code committee as part of the American National Standards Institute (ANSI). Until then, safety and design issues were the responsibility of the manufacturers. Three changes were made at the suggestion of the committee that drastically improved passenger safety. Brakes and safety switches were created so the escalator could be stopped during power outages, mechanical failures, or when passenger's clothing became stuck in the machine. Handrails and balustrades (side panels) were extended past the comb plates; this modification allowed passengers to grasp the handrail before they stepped onto the escalator, giving them time to adjust to the speed and making it easier to get on and off. Also, this extension moved the point where the handrail entered the balustrade at the floor farther from the riders. Many injuries had occurred when hands, feet, or clothing became caught at the joint. The third change came in the 1930's, when metal treads replaced the original wooden ones. The metal steps hold up better over time and break less often than wood. Wooden treads also had wider-spaced grooves that objects such as high heels often got stuck in.

Reno died on June 2, 1947, in Pelham Manor, New York. He was buried alongside his parents and siblings in the family plot in Washington, D.C. Reno and his wife had no children.

IMPACT

Reno began developing the idea of a moving staircase, or inclined elevator, at the age of sixteen. Some Reno escalators remained in operation in the Boston subway system and Philadelphia department stores through the 1990's. Many of Reno's ideas are still part of the modern-day escalator. He invented the early comb plate to clean the stairs, and the moving covered rubber handrail. In the 1950's, the U.S. Patent Office decided that "escalator" had become part of the vernacular to mean any moving staircase, and the word was lowercased. Macy's downtown New York City store still has wooden escalators in use. Hong Kong, on the other hand, has the largest modern escalator system in the world, with over half a mile of tracks.

—*Jennifer L. Campbell*

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See also: Elisha Graves Otis; Frank J. Sprague.

CHARLES FRANCIS RICHTER

American seismologist and physicist

Richter is best remembered for developing a scale that measures the energy released by an earthquake. He was a pioneer in seismology and was instrumental in developing a database of all earthquakes that occur worldwide every year.

Born: April 26, 1900; near Hamilton, Ohio
Died: September 30, 1985; Pasadena, California
Also known as: Charles Francis Kinsinger (birth name)
Primary fields: Geology; physics
Primary invention: Richter scale

EARLY LIFE

Charles Francis Kinsinger was born on a farm near Hamilton, Ohio, north of Cincinnati. His father, Frederick William Kinsinger, a farmer, and his mother, Lillian Anna Richter, a schoolteacher, were married on July 15, 1891, in Butler County, Ohio. Charles's sister, Margaret, was born in 1892, but their parents divorced shortly after

Charles Francis Richter. (California Institute of Technology)

her birth. Their parents remarried before Charles's birth in 1900, but, unfortunately, the second attempt at matrimony was no more successful than the first. After separating from her husband, Lillian resumed using her maiden name and changed her children's names to Charles Francis and Margaret Richter. Returning to live in her father's household, she raised her children in Ohio until the death of her mother in 1907 prompted her father to move his family to Los Angeles, California, where he purchased a house in the Wilshire district.

Accounts of Charles Richter's early childhood family life indicate that he and his sister were educated at home while they were in Ohio but sent to Hobart Boulevard School when they arrived in Los Angeles. These accounts also depict a dysfunctional family in which his mother was extremely attached to her father. Charles, who had survived a bout of cholera when he was fifteen months old, was a small, thin boy, shy at school, lonely, and dominated by his extremely assertive sister at home. (Margaret's aggressive personality, in some ways, served her well; in an era in which women did not commonly pursue an advanced degree, she ultimately earned a Ph.D. at the prestigious Stanford University.)

Academically, Charles did well in public school and was soon transferred to a preparatory school where he developed a taste for astronomy, chemistry, mathematics, and physics. He performed very well in high school, and after graduating at the age of sixteen in 1916, he was accepted at Stanford University, where he obtained his bachelor's degree in physics in 1920 and his Ph.D. in 1928.

Although his intellectual assets served him well, Richter was so afflicted with depression, nervous breakdown, and mental confusion that he spent a year (1920-1921) in a private sanatorium under the care of a psychiatrist, Dr. Ross Moore. At Moore's suggestion, Richter put aside his academic work temporarily while he took a series of jobs (clerk in a hardware company, messenger for the Los Angeles County Museum) in order to gain a degree of financial (and social) independence from his mother. Moore also encouraged him to take up writing as a way to explore his emotions, sparking in Richter a love of poetry that lasted throughout his life. (The vast majority of the poems Richter wrote have been preserved in his personal papers, which he bequeathed to the California Institute of Technology library.)

LIFE'S WORK

In 1922, Richter returned to Stanford and tackled the research he needed to complete his doctorate in physics. After receiving his doctorate in 1928, Richter, who had been an isolated and lonely student, was invited to a friend's house where he met divorcée Lillian Brand. They were married on July 19, 1928. Ignoring the advice of his psychiatrist to separate himself from his mother's influence, Richter took his new family, which included Lillian's two-year-old son, Reginald "Butch" Floyer Saunders, Jr., to live with his mother and sister. Predictably, the arrangement was a social disaster; Richter's wife, mother, and sister argued continuously.

Fortunately for Richter, his professional life was more successful. At the end of 1927, he had been hired as a part-time research assistant at the Caltech Seismological Laboratory near Pasadena, under the direction of Robert Andrews Millikan. As soon as he received his Ph.D., Richter was hired full-time, acquiring at once a stable position and access to the emerging science of seismology that became his lifelong passion. Rarely do people spend their entire lives working at the same place. Richter was one of these rare people, remaining at Caltech until he retired in 1970.

The founding of the Caltech Seismological Laboratory in Pasadena made good sense in light of the fact that many earthquakes had occurred on the San Andreas

Fault in California. Under Millikan, a physicist, Harry Wood, an astronomer, Hugo Benioff, a former astronomer and newly appointed seismologist, and John Anderson, an engineer, the laboratory flourished. Creating and maintaining an almost perfect research atmosphere, the laboratory encouraged its members to achieve their best. All scientists would gather at 10:30 A.M. and 2:30 P.M. for coffee and at noon for a game of bridge. These daily meetings would keep everyone aware of the progress made in each scientist's research. Problems would be discussed and solutions offered.

Thanks to the new and precise seismometer that Wood and Anderson created, a network of seismic stations, each equipped with a seismometer, was put into place. These seismometers recorded the basic data necessary to create a catalog of earthquakes. The successes, technological advances, and energetic research projects of the Caltech Seismological Laboratory stimulated other research institutes, such as the Seismology Institute of the University of California, Berkeley, the Lick Observatory of San Jose, and St. Louis University, to a healthy competition in which the science of seismology flourished.

As the laboratory grew, new well-known geophysicists joined the staff. Among these new employees was Beno Gutenberg, a Jewish German seismologist who had received from Caltech a job offer he could not turn down; the salary and living conditions in California were excellent, while the situation in Germany was worsening for Jews. Upon his arrival in 1930, Gutenberg immediately teamed up with Richter in the difficult task of measuring earthquakes. They published their research in four scientific papers that studied the nature of the seismic waves, the way they reflect and refract, and how they move in the Earth's interior. Acknowledging the partnership that both scientists developed over the years, many researchers believe that the Richter scale, used for measuring the magnitude of (the amount of energy released by) an earthquake, should be called the Gutenberg or Gutenberg-Richter scale. In an interview in 1979, Richter himself said that the term "somewhat underrates Gutenberg's part in developing it for further use." Nevertheless, Richter is credited with having produced the scale, which was developed and used beginning in 1932.

THE RICHTER SCALE

Until the 1930's, seismologists measured earthquakes by examining the damage they caused to human-made and natural structures. This idea of categorizing earthquakes based on their visible impact on the surface of the earth was first systematized in 1783 by Pompeo Schiantarelli, who constructed his scale based on observations of the damage caused by earthquakes in Calabria, in the southern part of Italy. Over the following 150 years, the idea was refined and expanded by generations of scientists. Schiantarelli's scale was updated in 1874 by Italian seismologist Michele de Rossi, whose work, in turn, was revised by Swiss scientist François-Alphonse Forel in 1881, resulting in the Rossi-Forel scale, which identified ten levels of earthquake intensity. Revised again by Giuseppe Mercalli in 1883, the ten-degree intensity scale was improved by a careful consideration of a wider diversity of building types and materials. In 1902, Mercalli expanded the intensity scale so as to include twelve degrees. Variations of the twelve-degree Mercalli scale were soon developed by Sergei Medvedev, Wilhelm Sponheuer, and Vit Kárníck in Europe. Today, the Modified Mercalli Intensity Scale is still used in the United States.

Charles Francis Richter developed a scale by which the relative intensity of earthquakes could be expressed based on a more direct indication of the energy they released. With the development of seismographs, it became possible to measure the actual movement of the earth rather than simply identifying the damaging impact. In 1931, Richter read a paper written by Japanese seismologist Kiyoo Wadati in which Wadati graphed the maximum ground motion of shallow earthquakes that had occurred in Japan using a logarithmic scale. This paper gave Richter the idea of developing a classification of earthquakes based on the size of the largest wave recorded on a seismogram. The Richter scale is a base-10 logarithmic scale; thus, for example, an earthquake that measures 7.0 has ten times the wave amplitude as an earthquake registering 6.0, and one hundred times the wave amplitude of a 5.0 magnitude earthquake. Each whole-number step in magnitude corresponds to the release of roughly thirty times more energy than the amount associated with the preceding whole-number value.

Wadati's innovative way to examine earthquakes was borrowed by Richter and applied by him to a multitude of earthquakes recorded by the Wood-Anderson seismometer at the Caltech Seismological Laboratory in Pasadena, California. Between 1931 and 1935, Richter worked on developing the arguments for using this type of measurement to classify earthquakes. The result of Richter's work was published in the *Bulletin of the Seismological Society* in 1935. The paper explained how to transform these wave measurements into a scale, now called the Richter scale.

The paper that introduced it to the scientific community was published in the January, 1935, issue of the *Bulletin of the Seismological Society of America*.

The Richter scale is logarithmic and has no upper limit (although no earthquake greater than 9.5 has ever been recorded). Richter most certainly did his share in the development of the scale, and the contributions of Richter and Gutenberg to the science of seismology in their book *Seismicity of the Earth* (1941) are such that their book is still valued today.

Richter was an avid reader of science-fiction books and an excellent linguist. He also enjoyed hiking in the Sierra Nevada. Year after year, he would spend his vacation in Sequoia and Kings Canyon National Parks. This communion with nature was a perfect match for his shy personality. At the beginning of his marriage, his wife Lillian would accompany him, but within a few years, her health deteriorated when she developed acute colitis. Charles and Lillian lived very independent lives while married. She visited France and Africa without her husband, while Charles spent a year alone in Japan as a Fulbright scholar.

In 1969, Charles and Lillian moved to Altadena in a house with very large windows from which Charles could see the San Gabriel Mountains, a region where he loved to walk. Shortly after their move, Lillian developed intestinal cancer. She underwent surgery in July, 1970, but the cancer spread and she developed lymphoma. She had another surgery in October, 1972, but had complications leading to her death on November 6, 1972.

Richter's health declined after the death of his wife, but he continued to work in the field of seismology. Even after his retirement in 1970, Richter returned to the laboratory every time there was a major earthquake in the region. He progressively needed more and more nursing help but remained in his house in Altadena. In July, 1984, he suffered a heart attack that required him to move to a nursing home. He died on September 30, 1985, of congestive heart failure and was buried in the Mountain View cemetery in Altadena next to his wife and his stepson.

Richter was an unconventional man, plagued throughout his life with neurological disorders that researchers today identify as probably being Asperger's syndrome, a condition that makes social interaction very difficult. Perhaps this helps to explain his loneliness and his lifelong preference for solitary pursuits, and may even relate to his commitment to nudism. However, while people often remarked on his isolation, they also thought that he was a "walking encyclopedia" because of his incredible capacity to memorize terms in physics and seismology, and many were impressed with his commitment to teaching.

IMPACT

An accomplished teacher and prolific researcher, Richter published extensively and mentored generations of graduate students from 1927 to 1970 while working at Caltech Seismological Laboratory. Richter is remembered as a pioneer in the science of seismology; his achievements are even more enormous when one considers that plate tectonics had not been discovered when he coauthored his treatise *Seismicity of the Earth* with Beno Gutenberg in 1941. Richter's legacy encompasses not only his magnitude scale that revolutionized the measurement of earthquakes but also the earthquake-monitoring system. He produced his long-term catalogs of earthquakes that researchers still use today.

—*Denyse Lemaire and David Kasserman*

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See also: John Milne.

NORBERT RILLIEUX

American engineer

Rillieux's invention of a vacuum evaporator revolutionized sugar refining. The process allowed sugar refineries to produce sugar more efficiently and with less intensive labor expenditure than ever before.

Born: March 17, 1806; New Orleans, Louisiana
Died: October 8, 1894; Paris, France
Primary field: Mechanical engineering
Primary invention: Multiple-effect vacuum evaporator

EARLY LIFE

Norbert Rillieux (RIHL-yuh) was born to Vincent Rillieux, a wealthy, French-born Louisiana engineer and sugarcane plantation owner, and Constant Vivant, a freed mulatto woman who had once been a slave on Rillieux's plantation. Norbert was a free Creole quadroon (a person of one-quarter black ancestry) and was baptized a Catholic. He was soon recognized as having a superior intellect and was sent to Catholic schools for his education. Eventually, his father sent him to France, where Norbert enrolled at the prestigious École Centrale in Paris to study engineering.

At age twenty-four, Rillieux became an instructor in applied mechanics at École Centrale, the youngest person ever to hold that position. By 1830, he had become an expert on steam power, publishing papers on the use of steam to operate machinery and on the economic benefits of this process.

LIFE'S WORK

In 1833, Rillieux returned to New Orleans and became involved in improving the labor-intensive sugar-refining process. The method in use at the time was called the "Jamaican Train," an expensive, inefficient process requiring a large labor force to perform dangerous, tedious steps to produce a product that was somewhat unpredictable in quantity and quality. The method involved pressing sugarcane juice out of the cane stalks, then heating the juice to induce evaporation and produce solid sugar. The process required workers, who were mostly slaves, to ladle the boiling hot juice from one kettle to another as the liquid thickened. Each kettle was heated by its own fire, so each pot had to be monitored to keep the sugar from burning, which occurred often. At the time, two other engineers named Howard and DeGrand had developed a device for evaporating the liquid portion of sugarcane juice. However, their process used steam inefficiently and produced a mediocre quality of sugar. Rillieux studied the process over the years and devised a method that could use condensation and evaporation more efficiently to convert the sugarcane juice into the coveted white sugar crystals.

Rillieux was aware of the British single-effect evaporator that was widely used in Europe to extract sugar from sugar beets. However, while it had some advantages over the more laborious refining method in use in the United States, it still made use of the several

Norbert Rillieux. (The Louisiana State Museum) open cauldrons and numerous fires to heat the juices. Rillieux realized that latent heat from one stage of the refining process could be harnessed for use in subsequent stages. Such harnessing could simplify the entire process, making it cheaper and safer to produce sugar crystals.

Rillieux invented a machine with a vacuum chamber with several pans stacked inside. The vacuum chamber enclosed coils for the condensation of the liquid in successive stages of the refining process, accomplishing the necessary multiple-effect evaporation. Because the boiling point of a liquid is lower in a vacuum than in the open air, the sugarcane juices could be boiled at a lower temperature. The steam rising from the pans at the lowest levels heated the pans at the top; thus, only one heat source was required for the process. This method reduced the amount of work involved because the liquid did not have to be shifted from one kettle to the next, and because the heat was under better control, the resulting sugar crystals would always be white instead of discolored.

Rillieux patented his multiple-effect evaporator system in 1843, and two years later his machine was successfully installed at a Louisiana plantation. In 1846, he persuaded several sugar manufacturers to use his machine, which had been perfected to the extent that it was capable of producing six thousand, twelve thousand, or eighteen thousand pounds of sugar per day. Manufacturers using the efficient machine were soon making such profits that the cost of the machine was quickly recovered.

Rillieux became quite wealthy and well known. The specter of the Civil War was looming, however, and by the 1850's he and all other free blacks living in New Orleans were facing increasingly negative attacks in the press, police harassment on the streets, and restrictions of various kinds that curtailed their lives in general. For a long time, Rillieux did not let these issues affect his interest in his work. When an outbreak of yellow fever threatened New Orleans, he devised a plan to halt the outbreak by eliminating the breeding grounds of the disease-carrying mosquitoes by draining the bayous surrounding the city and by improving the city's sewer system. When he presented his plan to the state legislature, there were those in office who disapproved of him, likely because of his ethnicity, and his plan was turned down. However, as the fever continued to spread for the next few years, some white engineers proposed an almost identical plan to the legislature, which was accepted.

The deteriorating conditions for free blacks in New Orleans finally pushed Rillieux beyond his limits. When an ordinance was passed requiring free blacks to carry a pass in order to travel, he returned to Paris in 1854. He lost some of his enthusiasm for engineering and instead got caught up in one of the fads of the time, Egyptology, studying Egyptian hieroglyphics with the family of Jean-François Champollion, the Frenchman who helped translate the Rosetta stone. Sometime during this period, Rillieux married Emily Cuckow.

At age seventy-five, Rillieux returned to sugar refining, attempting to solve the problems of extracting sugar from sugar beets. He patented a new system for this process; however, the French would not accept his invention, and he ultimately lost all the rights to his French patent. He died at the age of eighty-eight and was buried in the churchyard of Per La Chaise.

IMPACT

Rillieux's vacuum evaporation system revolutionized sugar refining, cutting the costs of production and thus

MULTIPLE-EFFECT VACUUM EVAPORATOR

Norbert Rillieux's invention of the multiple-effect vacuum evaporator for the improvement of sugar making helped establish the modern sugar industry. His machine used steam heat to evaporate water and consisted of apparatuses to heat and cool sugarcane juices in order to remove the moisture and leave crystallized sugar. The heater clarified the sugarcane juices to prepare them for the evaporation process. The evaporating pans, or boilers, were cylindrical, with the lower half of each extending to a chamber with a tube that connected each to the other chambers. This was to allow for the flow of water produced by vapor condensation. As the juices were heated and partly evaporated, the vapors from the juices in the lower pans rose to heat the juices in the upper pans. A fan blower created a current of air to cool the juices, producing the needed condensation.

While his invention was based on a sound chemical engineering principle, Rillieux was the first to put the principle to practical use. By using a single heat source to do the work that had previously been done by several heat sources, Rillieux opened the way for many other practical applications of his invention. Eventually, other industries used his invention in processes that required the evaporation of large amounts of water from a solution, such as producing salt from seawater, or even producing salt-free water.

decreasing the retail price of sugar. The principles of the process also changed the way that such products as condensed milk, gelatin, soap, and glue were manufactured. Rillieux's basic invention has also been used by industries that recover waste liquids, such as paper-manufacturing plants and distilleries, and that process petrochemicals. Called a scientific genius who was ahead of his time, Rillieux invented a system that has had widespread applications.

—Jane L. Ball

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See also: Sir Henry Bessemer; Clarence Birdseye.

John Augustus Roebling

German American civil engineer

Roebling perfected the manufacture of wire rope in the United States, was one of the pioneers in the development of suspension bridges using those cables, and was the designer of the Brooklyn Bridge, among other landmark structures.

Born: June 12, 1806; Mühlhausen, Prussia (now in Germany)
Died: July 22, 1869; Brooklyn Heights, New York
Primary fields: Architecture; civil engineering
Primary inventions: Wire cable; suspension bridge

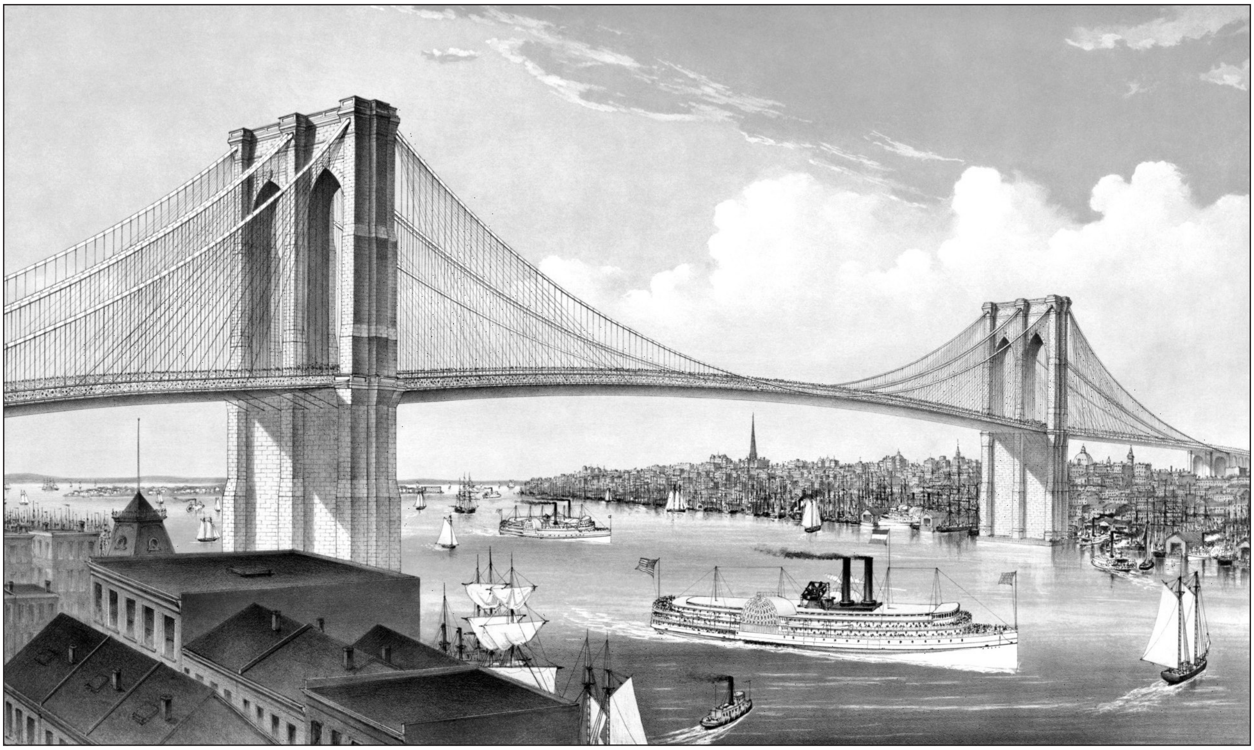
Early Life

John Augustus Roebling was the youngest son of Christoph Polycarpus Roebling, who owned a tobacco shop in Mühlhausen, Prussia (now in Germany) and Friederike Dorothea (Mueller). The young Roebling was educated in the public *Gymnasium* in Mühlhausen and pursued his studies in architecture and engineering at the Royal Polytechnic Institute in Berlin, where he also studied under the famous German philosopher Georg Wilhelm Friedrich Hegel. After graduation in 1826 with a degree in civil engineering, Roebling worked for three years building roads for the Prussian government in Westphalia. In 1831, with his brother Karl, Roebling led a group of fifty-three emigrants to America, and eventually into western Pennsylvania, where they founded a utopian community near Pittsburgh that they named Saxonburg. Growing bored with life as a farmer after a few years, however, Roebling went to work for the state of Pennsylvania as a surveyor and engineer on dams and bridges, at a moment when transportation projects were exploding across the country and the need for engineers was great. In 1841, he developed a method of spinning wires together to form cables (rope was previously employed on many bridges), and soon he began to manufacture these cables, at first in a workshop behind his house in Saxonburg and eventually in a plant he relocated in Trenton, New Jersey, the first wire rope factory in America.

Life's work

Roebling's career as a designer and builder of bridges actually began in 1845, when he won a competition for an aqueduct over the Allegheny River in Pittsburgh and built a suspension system using his own manufactured cable. In the remaining quarter century of his life, Roebling would plan and construct a dozen aqueducts and bridges, culminating in the Brooklyn Bridge, across the East River in New York City, completed by his son Washington fourteen years after its designer's death. (Washington Roebling had graduated from the Rensselaer Polytechnic Institute in 1857, and for the next dozen years—minus the time he served as an officer in the Union Army building bridges during the Civil War—worked side by side with his father.) Gifted with an inquisitive and philosophical mind, for more than twenty years John Roebling designed and built some of the longest and most beautiful suspension bridges in America. He worked on the Brooklyn Bridge for more than a decade. In three furious months in 1867, he produced all his drawings and his formal proposal for the bridge, but a ferry accident crushed his foot just after construction had begun in 1869, and he died of complications (tetanus, or lockjaw) several weeks later. At his death, he was worth more than a million dollars. Washington Roebling took over the construction of the bridge at the age of thirty-two and finished it in 1883, in the greatest celebration New York City had ever seen. The Roeblings perfected modern suspension bridge technology, and the cables they manufactured made these suspension bridges possible. John A. Roebling's Sons continues to operate to the present day.

Suspension bridges had been the subject of Roebling's thesis at the Royal Polytechnic Institute, and they continued to be a lifelong passion. Suspension bridges were appearing in Europe just as Roebling was growing up; the prototype for the Brooklyn Bridge was Thomas Telford's Menai Bridge in Wales, the first monumental metal suspension bridge (constructed from 1819 to 1826). Roebling saw the suspension bridge as the perfect balance of nature, and the cables he manufactured gave the bridges both their strength and structure and their beauty. Besides operating the first wire rope factory in America, Roebling devised a new method of stringing the cables across a river and invented a unique anchorage system for the cables on shore. In the same year he completed the Allegheny Aqueduct, Roebling built the Smithfield Street Bridge across the Monongahela River in Pittsburgh, and by 1850 he had constructed six suspended structures using his wire cables and had established the successful cable plant in Trenton.



John Augustus Roebling's Brooklyn Bridge. Upon completion in 1883, it was the longest suspension bridge in the world, spanning about 1,595 feet. (Library of Congress)

Each structure Roebling built seemed to be an improvement on the previous one. The Lackawaxen Aqueduct (completed in 1848) was a 535-foot-long suspension bridge over the Delaware River in northeastern Pennsylvania that would become a prototype for the Brooklyn Bridge. His Niagara Falls Bridge (1855), a railroad bridge connecting the New York Central Railroad and Great Western Railway of Canada over the Niagara River, spanned 825 feet. His Cincinnati-Covington Bridge (1866) had a main span of 1,057 feet over the Kentucky River, in a gorge deeper and wider than the Niagara. Renamed the John A. Roebling Suspension Bridge in 1984, the Cincinnati-Covington Bridge was the first to utilize both vertical suspenders and diagonal stays fanning out from either tower (Roebling would next employ those features on the Brooklyn Bridge), and it would be the longest suspension bridge until the completion of that more famous structure across New York's East River, the crowning achievement of Roebling's brief but intense engineering life.

IMPACT

Roebling's career represents a near-perfect collision of genius and environment. It is clear from his multiple achievements—as inventor, designer, and manufacturer—that his talents were unlimited. If he can be compared to any designer before him, as both artist and inventor, it would have to be the Italian Renaissance painter Leonardo da Vinci. Obsessed with his vision, however, Roebling was also a distant and impersonal husband and father. Genius would have taken him far in any age, but his accomplishments came in part because he began to work at a time when transportation projects (the first roads and railways) were multiplying in the United States and there was a need for innovative thinkers. Money was abundant—President Andrew Jackson had authorized almost $100 million for public engineering projects the year before Roebling immigrated to America—and Roebling tapped the need for innovation in design and engineering.

The suspension bridges Roebling planned and built would last for a long time, and his achievements in design and structure would influence a century of civil engineers. It is important to remember that Roebling's bridges, like the tools and machinery he invented and manufactured, were all handmade, and that they were produced during what is called "the horse and buggy days," a period before the advent of the technology that would be taken for granted in the twentieth century. To give a perspective to Roebling's accomplishments, the

THE BROOKLYN BRIDGE

The Brooklyn Bridge, which crosses New York's East River and connects the boroughs of Manhattan and Brooklyn, has been painted, photographed, and written about as often as any American icon. Writers and artists for more than a century have tried to capture the bridge's mystique: from the novelist John Dos Passos (*Manhattan Transfer*, 1925) and the poet Hart Crane (*The Bridge*, 1930), to painters such as Joseph Stella, Georgia O'Keefe, and John Marin, to photographers Edward Steichen, Berenice Abbott, and Walker Evans. The Brooklyn Bridge has become a symbol, comparable to those other monuments of New York City, the Statue of Liberty and the Empire State Building, and like them a structure that captures at once both America's power and its beauty.

John Augustus Roebling's major achievement in America was the use of wire rope in suspension bridges. The Brooklyn Bridge had four bundles of steel wires hanging from two stone towers anchored in the earth at both ends of the bridge with twenty-three-ton plates embedded in solid masonry foundations weighing 44,000 tons. Each of these four bundles carried 5,296 steel wires a distance of 3,578 feet. The unique design of the Brooklyn Bridge cable was that, instead of being woven like rope, the wires were arranged in a parallel fashion, thus reducing the stress. Roebling's improvements in the construction of the caissons and the design of the diagonal cable stays further added to the permanence and beauty of the bridge.

Roebling was the creator of this American icon. From the massive Gothic towers and their inviting archways, to the ways in which the bridge integrates its unique combination of steel and masonry, to the geometric beauty of its lines (such as the intersection of cables and suspenders), the Brooklyn Bridge is finally the product of the genius of John Roebling and combines his many gifts as designer, engineer, and architect. Few artists are able to leave such a symbol as their final legacy, and one that transcends its materials. The Brooklyn Bridge is somehow both mathematical and spiritual, an architectural structure that fuses technology with art to become what the late New York playwright Arthur Miller once called "steel poetry." Its Gothic stone towers draw viewers to some medieval past, but its use of steel points forward to the technology of the next century. Few structures in America are comparable to its power and grace, and it was only possible because of Roebling's designs and inventions, powerful vision, and multifaceted talents.

Brooklyn Bridge was halfway completed when the Battle of Little Bighorn was fought in Wyoming in 1876, and many of the revolutionary inventions of Alexander Graham Bell and Thomas Alva Edison came during the time the bridge was being constructed. Roebling was one of a handful of American designers and inventors who led the way from a frontier nineteenth century America into the modern twentieth century.

—*David Peck*

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See also: Peter Cooper; Stephanie Kwolek; Joseph Monier; George Stephenson; John Stevens; Faust Vrančić.

HEINRICH ROHRER

Swiss physicist

The collaborative research work of Rohrer and Gerd Binnig led to advancements in microscopy that enabled scientists to see objects as tiny as individual atoms. Their scanning tunneling microscope (STM) generated three-dimensional images of material surfaces that helped researchers determine the size and form of atoms and molecules, defects and abnormalities on surfaces, and how chemicals interact with materials. The STM soon became standard equipment in laboratories worldwide.

Born: June 6, 1933; Buchs, St. Gallen, Switzerland
Primary field: Physics
Primary invention: Scanning tunneling microscope

EARLY LIFE

Heinrich Rohrer (HIN-rihk ROH-rur) was the third child born to Hans Heinrich and Katharina Ganpenbein Rohrer. His twin sister was born a half hour before him. His father worked as a distributer of manufactured products. Young Rohrer felt a special closeness to his mother, who always encouraged him to do his best and supported and assisted him when times were difficult.

Rohrer's childhood was carefree and delightful. He enjoyed playing a variety of games with his siblings and friends, doing farm work, and attending school. When he turned thirteen years old, his family moved from the rural country setting of Buchs, Switzerland, to the urban lifestyle of Zurich.

During his school years, Rohrer developed a strong interest in classical languages and natural sciences, particularly physics and chemistry. After enrolling at the Swiss Federal Institute of Technology in Zurich in 1951, he decided to pursue a degree in physics and earned a bachelor of science in that discipline in 1955. During that time, he was taught and influenced by Nobel laureate Wolfgang Pauli, who had discovered the Pauli exclusion principle for electrons in atoms.

In the fall of 1955, Rohrer began work on a doctoral degree in physics at the institute. Under the direction of Jörgen Lykke Olsen, he made intricate measurements on materials at the critical point where superconductivity was induced by a magnetic field. Since the measurements made with mechanical transducers were so sensitive to the slightest vibrations, Rohrer had to do his work during the early morning hours when Zurich was quiet. As a member of the Swiss army, his Ph.D. work was occasionally interrupted as he participated in basic training in the mountain infantry. He earned his Ph.D. in experimental physics in 1960.

During 1960-1961, Rohrer worked as a research assistant at the Swiss Federal Institute of Technology. In the summer of 1961, he married Rose-Marie Egger, who helped him to settle down. For their honeymoon, they traveled to the United States, where Rohrer carried out postdoctoral research at Rutgers University for two years on the thermal conductivity of type-II superconductors.

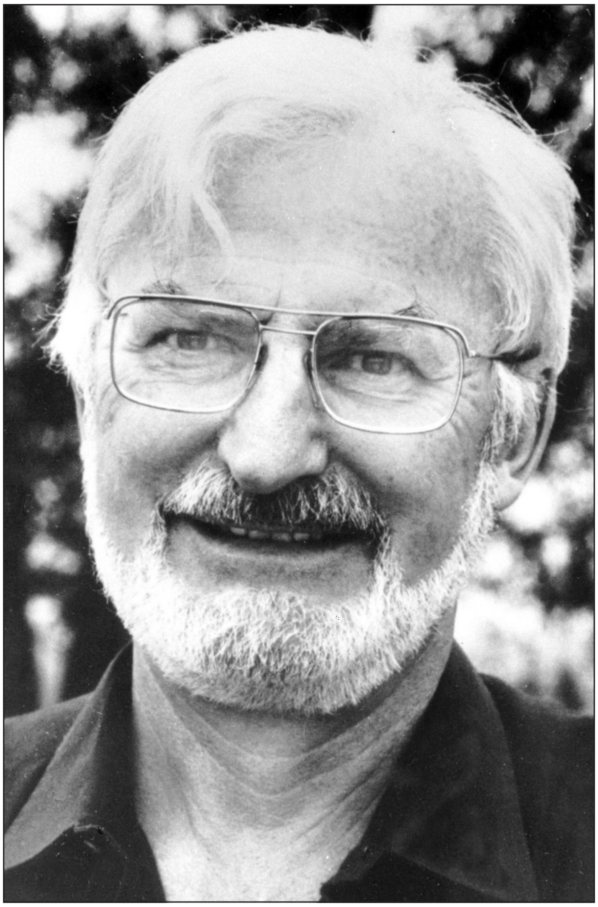
LIFE'S WORK

In 1963, Rohrer and his wife returned to Switzerland. Shortly thereafter, Rohrer was offered a research position with the recently founded International Business Machines (IBM) research laboratory in Rüschlikon, Switzerland, under the direction of Professor Ambros Speiser. His initial research work concentrated on changes in the thermal, electrical, and magnetic properties of nonmagnetic systems that contain small amounts of magnetic impurities. Such systems are referred to as Kondo systems. His focus was on Kondo systems exhibiting magnetoresistance in pulsed magnetic fields.

By 1969, Rohrer was working with Keith Blazey on optical experiments associated with antiferromagnets, which led him to the study of magnetic phase diagrams, phase transitions, and critical phenomena. During the 1974-1975 academic year, Rohrer took a sabbatical leave from IBM to do research on nuclear magnetic resonance with Alan King and Vince Jaccarino at the University of California, Santa Barbara. Prior to and following the sabbatical, Rohrer, his wife, and their two daughters, Doris and Ellen, took extended camping trips throughout the United States.

After returning to IBM, Rohrer became interested in the complex atomic structures of the surfaces of various materials. At the time, little was known about the nature of surface atoms. After German physicist Gerd Binnig joined IBM in 1978, he and Rohrer began exploring oxide layers on metal surfaces. Initially, they pursued the development of a spectroscopic probe to examine the surfaces. In the process, they invented a new type of microscope, the scanning tunneling microscope (STM), with the capability of examining the atomic structure of metal and semiconductor surfaces. Their idea was to scan the surface using the tip of a needle probe at a height of only a few atomic diameters above the surface.

In the development of their invention, Rohrer and Binnig encountered several problems. The most serious challenge was that the tip of the probe was very sensitive to any vibrations, a problem similar to that faced by Rohrer when he was collecting data during his Ph.D. research. Since the required magnification to see atoms was on the order of 100 million, any interference from vibration or noise would greatly distort the produced image. Using Rohrer's previous experience, he and Binnig decided to shield the probe from disturbances by conducting their experiments on a heavy stone table set on top of inflated rubber tires and by resting the STM on copper plates positioned between magnets. Any movement of the copper plates in the magnetic field would produce an induced current in the copper, and the interaction between the current and the field generated a feedback effect that damped any motion of the plates. Vibrations were reduced to the point where a vertical resolution on the order of one-tenth the diameter of an atom was achieved. Rohrer and Binnig built their first STM in 1981.



Heinrich Rohrer. (©The Nobel Foundation)

THE SCANNING TUNNELING MICROSCOPE

A scanning tunneling microscope can produce a three-dimensional image of individual atoms that reside on the surface of a metal or a semiconductor. The tip of a needle, the STM probe, is scanned over the surface of the material of interest just a few atomic diameters above the surface. After a voltage is applied between the tip of the probe and the surface, a current flows between them as a result of the tunneling effect. Tunneling is a quantum mechanical effect. Electrons have a wavelike nature that causes them to create a spreading cloud, or aura, as they are emitted from the surface of a material. When the electron clouds from two closely spaced surfaces overlap, the electrons tunnel from one cloud to the other.

Heinrich Rohrer and Gerd Binnig suspended their STM probe on springs inside of a vacuum to scan the surface of the material of interest by using the tunneling effect. As the tip of the probe nears the sample, the electron clouds of the probe and material surfaces overlap and a tunneling current flows. Using a feedback mechanism, this current is used to keep the tip of the probe at a constant height above the sample surface. This enables the tip to follow the contours of the individual atoms of the scanned surface. The STM detects any minute variations in the distance electrons travel between the probe and the surface. This information is saved by a computer in a data file. Using these data, a computer algorithm processes the motion of the tip to produce a three-dimensional, high-resolution image of the electrical topography of the surface of the sample material.

By the mid-1980's, all but the vacuum chamber of the STM could fit into the palm of a human hand. The STM has opened up entirely new fields for studying the structure of matter. It has proven invaluable in studying the surfaces of semiconductors, metals, and biological samples, including viruses. The STM has even been reconfigured to manipulate molecules and atoms at the nanoscale level (billionths of a meter). Researchers and product developers can then observe what happens at the molecular and atomic levels, and by moving atoms from place to place, they can manufacture and modify useful products.

After Binnig and Rohrer were awarded the Nobel Prize in Physics in 1986, along with Ernst Ruska, who had invented the electron microscope, Rohrer was appointed as an IBM fellow, the most prestigious technical position at IBM. In this position, Rohrer had the freedom to pursue whatever research projects he felt were most important for IBM. During 1986-1988, he managed the Physical Sciences Department of the IBM Rüschlikon research laboratory. By 1987, Rohrer's research group had developed an STM the size of a human fingertip, with a resolution capability for seeing atomic-scale objects to within $^{1}/_{25}$ the diameter of a typical-sized atom.

Rohrer retired from IBM in July, 1997. Afterward, he participated in research appointments at the Consejo Superior de Investigaciones Cientifcas (CSIC) in Madrid, Spain, and at the Riken Institute and Tohoku University in Japan. His research focus became nanoscience, how matter behaves at submicroscopic levels on the order of a billionth of a meter in size, and nanotechnology, research and technology development at the atomic and molecular levels that allows the ability to manipulate particles on the atomic scale. Rohrer has been instrumental in encouraging the use of the STM as a major tool in nanotechnology to control atoms and molecules to help modify and manufacture products at the nanoscale level.

IMPACT

Since the invention of the first microscope, scientists searched for improvements for exploring the microscopic world. Optical microscopes were limited by the wavelength of light, which is approximately two thousand times larger than the diameter of a typical atom. Electron microscopes achieved much higher resolution due to the shorter wavelength of electrons in forming images, but they could not resolve images smaller than about five times the diameter of a typical atom. Being very familiar with the field of microscopy, Rohrer set a goal to image microscopic particles. During his many years of research, he had developed both the theoretical and experimental foundations and insights that were necessary to be successful.

In 1978, Rohrer and Binnig began their quest to invent an atomic microscope. Displaying foresight and fierce tenacity, the two solved a number of significant problems, particularly vibrational and noise sensitivity of their imaging probe, in the development of their scanning tunneling microscope. After numerous changes and additions to their experimental setup and equipment, their invention came to fruition in 1981. Only five years later, they were awarded the Nobel Prize in Physics.

Rohrer's practical abilities, inventive genius, and scientific contributions were rewarded with numerous prestigious awards in addition to the Nobel Prize. In 1984, Rohrer and Binnig received the King Faisal Prize and the Hewlett Packard Europhysics Prize for their invention of the STM. Rohrer was presented the Elliott Cresson Medal of the Franklin Institute in Philadelphia in 1987. In 1994, he was inducted into the United States National Inventors Hall of Fame. He has also been awarded numerous honorary doctorates by several universities throughout the world.

—*Alvin K. Benson*

Further Reading

Chen, C. Julian. *Introduction to Scanning Tunneling Microscopy*. 2d ed. New York: Oxford University Press, 2007. This very readable book discusses the invention of the STM and the basic operating principles of scanning tunneling microscopy and atomic force microscopy. The theoretical basis and the relationship between tunneling and interaction energy are presented, along with the experimental facts. The use of the STM in biological research and its use in the manipulation of individual atoms in nanotechnology are presented. Bibliographical references and an index are included.

Dardo, Mauro. *Nobel Laureates and Twentieth-Century Physics*. New York: Cambridge University Press, 2004. Contains biographies and revealing personal anecdotes about the lives and events of the most famous physicists of the twentieth century. The work of Rohrer is presented and discussed by Dardo and by Rohrer himself. The significance of lasers, superconductivity, Bose-Einstein condensates, the STM, and other scientific breakthroughs of the twentieth century are highlighted. An index and bibliographical references are included.

Foster, Adam Stuart. *Scanning Probe Microscopy: Atomic Scale Engineering by Forces and Currents*. New York: Springer Science, 2006. Written in a tutorial style, the book explains the basic principles underlying atomic probe techniques that were pioneered by Rohrer and Binnig. Examples are presented of the theoretical concepts by using state-of-the-art simulations that allow comparisons with experimental data. Bibliographical references and an index are included.

Margulis, Lynn, and Eduardo Punset, eds. *Mind, Life, and Universe: Conversations with Great Scientists of Our Time*. White River Junction, Vt.: Chelsea Green, 2007. The authors interviewed thirty-six scientists, one of whom was Rohrer, about their thoughts and ideas regarding some of the most important concepts influencing their fields today. Rohrer gives insights into research in atomic and subatomic phenomena and applications to everyday uses. An index and bibliographical references are included.

See also: Gerd Binnig; Ernst Ruska.

WILHELM CONRAD RÖNTGEN

German physicist

Röntgen discovered X rays and pioneered their use in imaging structures inside the living human body. Medical X rays are considered to be one of the ten greatest discoveries in medical science.

Born: March 27, 1845; Lennep, Prussia (now Remscheid, Germany)
Died: February 10, 1923; Munich, Germany
Primary field: Physics
Primary invention: X-ray tube

Early Life

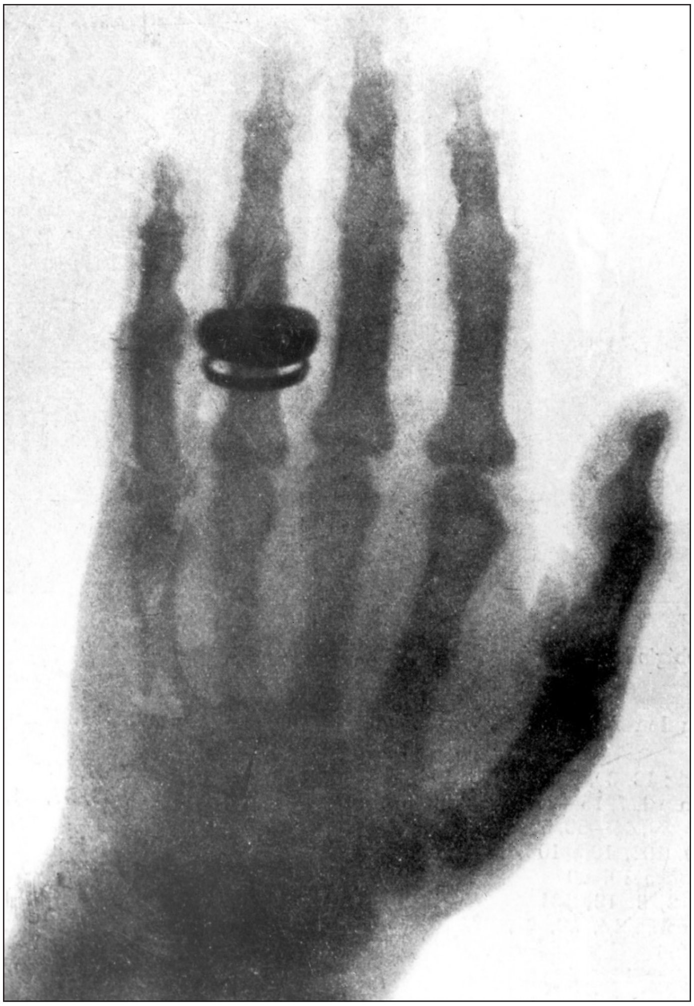
Wilhelm Conrad Röntgen (VIHL-hehlm KAHN-rad RUHNT-guhn) was the only son of Friedrich Conrad Röntgen, a textile manufacturer and merchant, and Charlotte Constanze Frowein of Holland. The family moved to Apeldoorn in Holland when young Röntgen was three years old. He attended a private boarding school there, and although he would rather be outdoors or working with his hands than studying, he did well enough to qualify to study at the *Gymnasium* (comparable to a U.S. college-preparatory high school).

His studies went well enough until crisis struck in 1862. A fellow student had drawn an unflattering caricature of a teacher. Röntgen knew who had done it, and the headmaster demanded that he reveal the culprit's name or face expulsion. Refusing to betray his classmate, Röntgen was not only expelled but also blacklisted, making it impossible for him to attend any other *Gymnasium* in Holland or Germany. Without a diploma from a *Gymnasium*, he could not enroll in a university in either country, so he studied for two and a half years at the Utrecht Technical School. Although this was not a college-preparatory school, he was able to pass the entrance examinations in 1865 and enroll at the Polytechnical School in Zurich, a route that would be followed thirty-one years later by Albert Einstein, who also ran afoul of the school system.

Röntgen studied mechanical engineering, receiving his diploma in 1868. One of his teachers, Professor August Kundt, became his mentor and sponsor and convinced him to change his studies to physics. Röntgen earned his Ph.D. only a year later. After receiving his degree, Röntgen became Kundt's assistant, largely because he was especially adept at constructing experimental equipment. While working in Zurich, Röntgen met his future wife, Anna Bertha Ludwig. In 1871, Kundt accepted a position at the University of Würzburg, and Röntgen went with him. Röntgen married Anna in 1872, and although they had no children, they adopted Anna's six-year-old niece in 1887.

LIFE'S WORK

Röntgen eventually separated from Kundt and struck out on his own. He did well, teaching at three universities and rising through the academic ranks. While at the University of Giessen, Röntgen demonstrated that moving a piece of insulating material, such as glass, in an electric field causes a magnetic field to appear in the insulator. This effect was predicted by James Clerk Maxwell, who had developed a set of equations known as Maxwell's equations, which contain all that is known about electricity and magnetism. Röntgen published this result in 1888 and later said that this was as important as his discovery of X rays, since it established that Maxwell's equations are correct. Also in the year 1888, he returned to Würzburg, but this time as department chair.



One of the first X-ray photographs, taken by Wilhelm Conrad Röntgen and showing his wife's hand. (Getty Images)

Röntgen was red-green color-blind. Some people with this problem become very keen observers in order to distinguish what others say are different colors. Röntgen became such an observer, and this helped him to become one of the best experimental physicists of his time. After examining Maxwell's equations, the famous scientist Hermann von Helmholtz predicted the existence of very penetrating short-wavelength radiation. Röntgen decided to look for these penetrating rays. In the fall of 1895, while studying cathode rays generated in Crookes tubes, he made a historic discovery.

Crookes tubes (named for the English chemist Sir William Crookes) are glass cylinders about the size of a one-liter bottle. An electrode is placed in each end, the tube is sealed, and the air is sucked out. When the air pressure is low enough and thousands of volts are placed across the electrodes, rays stream from the cathode (the negative electrode). Although the rays are invisible, their path can be traced by seeing where they hit on a fluorescent screen. Röntgen hypothesized that when cathode rays struck a target, they would create Helmholtz's penetrating radiation. For a detector, Röntgen had prepared a card painted with barium platinocyanide, which glowed when exposed to ultraviolet light. Röntgen darkened the room and completely covered the Crookes tube with black cardboard to block all light from the tube. When he turned on the high voltage to the tube, a flash of light from the chemically coated card caught his eye. He placed a sheet of paper in front of the card, and then a book, and then a wooden board;

THE X-RAY TUBE

When he discovered X rays in 1895, Wilhelm Conrad Röntgen was using a Crookes tube, named for the English chemist Sir William Crookes. A Crookes tube is a glass bulb from which almost all of the air has been evacuated. It is about as long as a large banana, but several times fatter, and it generally has electrodes sealed inside at the two ends. Producing X rays requires tens of thousands of volts. Using a circuit similar to that used by a modern automobile to generate high voltage for the spark plugs, the high voltage for the X-ray tube began with a storage battery equipped with a vibrating switch that turned the current on and off many times per second, since only changing current can be transformed. This current was fed into an induction coil and transformed into high voltage. When the high voltage was connected to the electrodes of a Crookes tube, invisible rays of some type streamed out from the cathode (negative terminal) and on through the Crookes tube. It was later discovered that these cathode rays are streams of high-energy electrons.

When some of these electrons struck the glass at the far end of the tube, the glass glowed green and produced X rays. More exactly, as electrons are brought to a stop in a target, such as an electrode or the glass wall of the tube, the decelerating electrons emit X rays. The positive electrode on the opposite end of the tube from the cathode is called the anode. Röntgen discovered that if the anode were made of a heavy metal such as platinum, more X rays were produced. X-ray photographs were produced by wrapping photographic film in lightproof paper, placing the object to be X-rayed on top of the film package, and then exposing the object and film package to X rays. Developing the film as normal camera film then revealed the shadowgraph called an X ray. Areas in the target that absorb most of the X rays, such as bone, appear whiter in the shadowgraph; areas in the target that transmit most of the X rays instead of absorbing them, such as muscle, appear darker.

Many laboratories had Crookes tubes along with the necessary electrical components and photographic facilities to make X-ray photographs. On February 8, 1896, just over one month from Röntgen's public announcement of X rays, Edwin Brant Frost in Dartmouth, Massachusetts, made an X ray of a fractured bone in Eddie McCarthy. Another early medical X ray was made by Professor John Cox of McGill University to locate a bullet that had festered for six weeks in a patient. It had previously escaped detection because it was lodged between the patient's tibia and fibula.

Within four months of Röntgen's public announcement about X rays, Thomas Alva Edison's company was selling X-ray kits. With such a kit, anyone could make X rays. Marie Curie and her daughter, Irene, voluntarily took an X-ray kit to the front lines in World War I. They used it to good effect on wounded soldiers. X rays have become so indispensable to modern medicine that every modern hospital is equipped with at least one X-ray machine.

the card continued to glow, demonstrating that the radiation was very penetrating. History was made when Röntgen held a lead disk in front of the screen. He saw not only the shadow of the lead disk but also the shadows of his finger bones.

In the culture of the times, seeing a skeleton was regarded as a premonition of death. Already meticulous by nature, Röntgen decided he needed to exercise extra care before announcing his discovery so that he would not be taken as a crackpot. Röntgen worked feverishly for six weeks to establish the properties of these newly discovered rays. He named them "X rays," with the *X* standing for unknown. He found that all substances were more or less transparent to X rays. Several substances such as calcium compounds and uranium glass fluoresced when exposed to the rays. X rays seemed to be a different phenomenon than light because Röntgen was not successful at reflecting or diffracting them. (Later, other scientists were successful at this.) X rays could not be a beam of charged particles like cathode rays because their path was not affected by a magnet. They could cause static electricity to leak away faster, so Röntgen concluded that X rays ionize air. Finally, photographic emulsions were sensitive to X rays. Röntgen used this property to make a shadowgraph of his wife's hand that showed a ring she was wearing.

On New Year's Day, 1896, Röntgen mailed copies of this X-ray picture titled, "Hand, mit Ringen" (hand with ring), along with an article describing his discovery of X rays to six prominent physicists. One of these pictures found its way into the newspaper, *Die Presse*, in Vienna on January 5, 1896. Röntgen became famous overnight. Some claimed the fame was undeserved and that his discovery was a lucky accident, but although it was happenstance that he saw the first glow, Röntgen's discovery was no accident. Had he not seen the glow, Röntgen would have next held the fluorescent screen close to the tube, according to his plan, and would have then seen the glow.

IMPACT

In addition to their use in medicine, X rays are used to authenticate art work, stamps, and coins. They are also used to reveal the crystal structure of minerals, to gauge the thickness of materials, to inspect welds, and to look for microscopic cracks in pipes. If X rays are used to strip inner electrons from atoms, and the electrons are then allowed to recombine with the ionized atoms, they will emit X rays that are characteristic of the chemical elements present. This technique, called X-ray fluorescence, can be used to detect trace amounts of various elements. Characteristic X rays have been used to identify elements on Mars and on the Moon.

Röntgen introduced a medical application of X rays with the publication of the X-ray photograph of his wife's hand, but, believing that medical X rays would be eminently useful, he never patented any aspect of the process, so others would be free to use it. Medical X rays have become so useful that their discovery is ranked as one of the most important discoveries in medical science. The first Nobel Prize in Physics ever awarded went to Röntgen in 1901. He donated the prize money to the University of Würzburg, but he got so flustered when speaking to an audience that he did not give a speech at the Nobel ceremony. Röntgen died of radiation effects at age seventy-eight. Although he received dozens of medals and over fifty honorary doctorates, he died nearly penniless.

In 1971, the English electrical engineer Godfrey Newbold Hounsfield led a group of scientists using a computer to guide the X-ray tube and to combine images. The result was a computed tomography (CT) scan. CT scans allow doctors to follow details inside a person through a series of computer-enhanced, stacked X-ray pictures. The scans are cheaper than magnetic resonance imaging (MRI), but MRIs do not expose the patient to radiation. Some tissues show up better with one technique, and some with the other, so it is most fortunate that both are now available.

—*Charles W. Rogers*

FURTHER READING

Friedman, Meyer, and Gerald W. Friedland. "Wilhelm Röntgen and the X-ray Beam." In *Medicine's Ten Greatest Discoveries*. New Haven, Conn.: Yale University Press, 1998. Readable account of Röntgen's discovery of X rays. Follows Röntgen's life afterward along with technological advances to CT scans.

L'Annunziata, Michael F. *Radioactivity: Introduction and History*. Amsterdam: Elsevier Science, 2007. The author gives several biographies of key players in the science of radioactivity. This approach shows how Röntgen's work fits in history.

Ouellette, Jennifer. *Black Bodies and Quantum Cats*. New York: Penguin Books, 2005. Ouellette uses history and pop culture to painlessly teach physics. Having read about Röntgen in chapter 18, readers will be drawn to read other vignettes as well.

Seliger, Howard H. "Wilhelm Conrad Röntgen and the Glimmer of Light." *Physics Today* 48, no. 11 (November, 1995): 25-31. An excellent account of Röntgen's discovery and subsequent study of X rays. Explains that the discovery was no accident: Had Röntgen not noticed the glimmer of the fluorescent screen, he would have seen the glow when he held the screen near the tube, as he had planned.

See also: William David Coolidge; Sir William Crookes; Thomas Alva Edison; Hermann von Helmholtz; Heinrich Hertz; Dorothy Crowfoot Hodgkin; Godfrey Newbold Hounsfield; Nikola Tesla.

SYLVESTER ROPER

American mechanical engineer

Although a career inventor—completing groundbreaking designs of sewing machines, furnaces, machine tools, and firearms—Roper is best remembered for pioneering the application of steam engine technology to bicycle design, developing the steam velocipede, a self-propelled two-wheeled vehicle, the precursor of the gas-powered motorcycle.

Born: November 24, 1823; Francestown, New Hampshire
Died: June 1, 1896; Cambridge, Massachusetts
Also known as: Sylvester Howard Roper (full name)
Primary fields: Automotive technology; mechanical engineering
Primary invention: Steam velocipede

EARLY LIFE

Sylvester Howard Roper was born on November 24, 1823, in the tiny southern New Hampshire hamlet of Francestown. Largely because the impact of Roper's most daring designs were not appreciated until decades after his death and because Roper himself, despite nearly seven decades of engineering initiatives, never filed for a patent nor pursued commercial sales of his numerous inventions, little is known about his early life. There is no record of his education—historians have assumed that Roper's father, an expert cabinetmaker, most likely apprenticed his son. Roper wrote years later of the education he received watching his father, how he came to be fascinated by mechanical design, by efficient machinery, and specifically by the manipulation of steam power to direct machine operation. Before he was fifteen, he had worked out a design of a small steam engine; before he was seventeen, he had designed a more powerful engine in an effort to up the speeds of steam locomotives, whose heavy iron construction compromised their speed.

Records indicate that by 1854 Roper had moved several times before settling in Roxbury, outside Boston, where he worked as a machinist. He never stopped pursuing individual design projects. During the Civil War, Roper, nearly forty and too old to enlist, worked at the Springfield Armory. He would find considerable financial security after the war as a gunsmith. Among his more notable inventions was the shotgun choke.

THE STEAM VELOCIPEDE

Although Sylvester Roper redesigned the steam velocipede from 1867 until his death, addressing specifically its handling problems and its inability to sustain long distances, it is the 1869 Roper steam bicycle that is perhaps his landmark achievement. (The model is currently housed at the Smithsonian Institution.) It represented the foundational design elements of Roper's conception of steam-powered two-wheeled transportation. By attaching a twin-cylinder steam engine with a boiler and firebox (a basic Franklin stove) along with a manually operated water tank to the existing frame of a standard bicycle of the era (with the traditional two wheels with hickory spokes and forged iron band rims), Roper ushered in the era of machine transportation, anticipating the evolution fifty years later of gas-propelled internal combustion engines. The contraption was not designed for comfort (the solid heavy wheels made for a strong vibration) or aesthetics. Rather, it was compact and fast.

Roper attached one cylinder to each side of the bike's frame, each connected in turn to the driving cranks on the rear wheel axle. He suspended a lightweight vertical boiler on springs between the wheels, with a small angled chimney pointing back from the top of the boiler at the rear of the bike's saddle. The twin-cylinder design was Roper's own, drawing on his concept of manageability given the velocipede's precarious balance. The boiler would act as the vehicle's water storage tank as well. The lower half of the boiler was the firebox, in which the crushed coal was fed. For safety, a flue with an adjustable angle helped the driver contain and control the fire. The rider operated by hand a small water pump mounted at the left forward side of the boiler just under the saddle and fed water as the steam was used. Oscillating steam-driven cylinders in turn pivoted on each side of the bike's frame next to the chimney. Connecting rods running to the rear axle generated the bike's momentum from the compressed steam from the stored water after it had been heated at extremely high temperatures (which made the ride a bit precarious for the driver who straddled the boiler). A cable attached to the handlebars controlled the throttle, and turning the cable counterclockwise actually activated the braking system. Although later designs would increase the capacity of the water tank, the early designs accommodated relatively short distances, three to five miles at speeds approaching 30 miles per hour.

LIFE'S WORK

Nearly immediately after the war ended, Roper returned to his first love: the potential of steam. Steam was being used to propel ships and trains, and stationary steam engines managed entire industrial plants. However, what intrigued Roper was the idea of developing lighter machines that could use steam power to revolutionize the concept of speed itself. He was particularly intrigued by the new pedaled velocipede (or bicycle) that, unlike earlier designs that had relied on being pushed by the rider's feet or that were notoriously unstable because they had a huge front wheel and a smaller back wheel, featured wheels of equal size and thus promised better mobility.

Between 1867 and 1869 (Roper kept few accurate records of his prodigious number of ongoing projects), Roper attached a twin-cylinder steam engine to the velocipede frame. The bicycle was significantly modified by Roper: The saddle was moved far up to allow for placing the firebox and the boiler between the wooden wheels. Although the design had its problems—not the least of which was an iron boiler with a charcoal fire operating at nearly 300° Fahrenheit suspended between the wheels and thus percolating between the legs of the rider—Roper was encouraged by the design. The redesigned bicycle was of course bulky—estimates put the weight at more than 160 pounds—and was by all reports uncomfortable to ride. The boiler water supply, under the rider's seat, was manually pumped at the forward side of the boiler. The heated steam maintained the vehicle's momentum.

The steam velocipede was remarkably safe. Roper had designed a kind of twist-grip control mechanism for the handlebar to control the steam throttle and in turn to propel the velocipede. Although not a particularly attractive design, the steam-powered "motocycle" (as Roper called it) offered what Roper had long been fascinated with: speed. Despite generating enormous numbers of complaints from Roxbury residents over the machine's noise (it spooked horses), Roper delighted in motoring about the streets. He claimed that his machine could outrun a horse and climb any hill. Attempts were made to curb Roper's street demonstrations; he was actually arrested once, but of course, because city ordinances had yet to address specifically the problems posed by such innovative designs, Roper never served time or paid a fine.

Over the next thirty years, Roper devoted enormous resources of time to renovating the bicycle's design. He also worked on a design for a steam-driven automobile and had built steam engines for yachts. Given his financial security (he had made a fortune as a gunsmith and later, with his son, in developing a machine capable of making screws), Roper pursued his design, making each of the ten subsequent redesigns lighter and, of course, faster. He became something of a regional celebrity, taking his motocycles to tracks, circuses, and fairs and performing exhibition runs in which he himself, despite his advancing years, did the riding, although the machines were known for routinely achieving "dangerous" speeds of more than thirty miles per hour.

In 1895, Roper approached the Pope Manufacturing Company for joint sponsorship of a project designed to make his steam-powered bicycle more practical and ultimately available for a mass market. Since 1878, Pope had aggressively worked to corner the bicycle market and had pioneered several cutting-edge technological innovations in bicycle design; by the time Roper teamed up with the company, it had established itself as the dominant producer of bicycles in America. With that financial backing, Roper produced what would be his last prototype, a revolutionary design that was sleeker (a much smaller boiler over the coal firebox) and lighter (just under 150 pounds) and capable, with its one-gallon water reservoir, of more than twenty miles in one filling of coal.

Eager to test the vehicle and promote it in the process, Roper, although past the age of seventy, accepted an invitation to test-drive the vehicle before an interested crowd at a small (one-third-mile) wooden bike track along the Charles River. On the morning of June 1, 1896, Roper made three routine exhibition laps. As part of the carnivalesque atmosphere, he challenged and then bested bike riders, who, of course, could not keep pace with his machine. Journalists attending that day recorded that Roper covered a mile in two minutes and twelve seconds. Roper, who told reporters that he had gone closer to 40 miles per hour the week before, was determined to push the speed. He instructed his assistants to rebuild the steam pressure. On his first lap—in which, eyewitnesses estimated, the machine achieved nearly 60 miles per hour—the machine began to wobble. Roper lost control and was thrown off the track and into a sandy bank that surrounded the track. He was dead before volunteers could get to him. Although his death was widely used as a cautionary lesson against the dangers of the newfangled speed machines, autopsy reports later confirmed that Roper had actually died of a heart attack and was dead before the crash.

IMPACT

Although Roper is credited historically (and rightfully) with being the world's first motorcyclist, his is a far more fascinating legacy. He was an inventor—and just that. In an expanding industrial era when inventing itself was deemed a profession and inventors emerged among the savviest capitalist entrepreneurs, flooding the American market with new gadgets that would propel some inventors not only to celebrity status but also to significant fortune, Roper stands apart. He spent close to seven decades pursuing his simple love of design, his fascination with tinkering. With his wide-ranging intellect (he was entirely self-trained), he completed a staggering variety of inventions without pursuing the patent protection or even the marketing potential that gave much lesser engineers reputation and vast fortunes. Restless, curious, fascinated by the intricacies of design itself, he was drawn to the traditional problem-solution approach of old-school technology. In that, he is a singular presence amid the fierce competitive marketplace of late nineteenth century industrial technology.

That said, Roper has found a secure place within the mythos of the motorcycle culture, his steam velocipede a clear precursor of the gas-driven motorcycles of a generation later. Much of his work anticipated innovations that would shape motorcycle technology in its earliest years. His was a vision that saw two-wheeled vehicle transportation as an expression of both speed and convenience. His tireless promotion of its technology in the face of conservative resistance to its novelty and to its evident danger marks him as an early proponent of what would become the free spirit and aggressive individuality associated with motorcycle riding. Indeed, it is his death that most defines his impact within motorcycle culture: At seventy-three, his heart burst at the very moment when his machine achieved unprecedented speed, the essence of the daring temperament that would become the signature of motorcycle enthusiasts.

—*Joseph Dewey*

FURTHER READING

Bacon, Roy. *An Illustrated History of Motorcycles*. Canton, Ohio: PRC, 1996. Detailed and handsomely illustrated survey of the cumulative improvements in motorcycle design. Provides accounts of Roper's early work and his multiple designs and links his steam-powered conceptuals specifically to the evolution of gas-powered motorcycles.

Dregni, Michael. *Spirit of Motorcycle*. Stillwater, Minn.: Voyageur Press, 2000. Lively anatomy of the motorcycle culture by one of the most respected pop cultural commentators. Although the book does not deal specifically with Roper, it positions the import of his work by tracing the place of motorcycles in music, film, and television.

Kimes, Beverly. *Pioneers, Engineers, and Scoundrels: The Dawn of the Automobile in America*. Warrendale, Pa.: SAE International, 2004. Important and highly readable account of the emergence of transportation technology at the turn of the nineteenth century. Includes Roper and motorcycle technology and sees motorcycles and automobile industries as intrinsically part of the same transportation revolution.

Pierson, Melissa Holbrook. *The Perfect Vehicle: What It Is About Motorcycles*. New York: W. W. Norton, 1997. A thoughtful critique of the motorcycle culture (unlike so many such studies that tend to trivialize the subject) that puts Roper's technological achievements within a cultural context. Places Roper as an early rebel who embodied the sense of freedom that the motorcycle represented.

Walker, Mick. *Motorcycle: Evolution, Design, Passion*. Baltimore: The Johns Hopkins University Press, 2001. Comprehensive survey of motorcycle technology (including Roper's designs) with helpful illustrations and glossary. Solid introduction to the concepts of Roper's engines. Designed for readers not versed in engineering and motor engine design.

See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; John Boyd Dunlop; Henry Ford; Charles Goodyear; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; André and Édouard Michelin; Ransom Eli Olds; Nikolaus August Otto; Stanford Ovshinsky; Ignaz Schwinn; Felix Wankel; Alexander Winton.

ERNST RUSKA

German electrical engineer

Ruska's pioneer work leading to the invention of the electron microscope made it possible for researchers in various fields of science, ranging from biology through medicine and chemistry, to develop much more precise knowledge of the microscopic world of organic cells and until-then mysterious structures of inorganic material.

Born: December 25, 1906; Heidelberg, Germany
Died: May 30, 1988; West Berlin, West Germany (now Berlin, Germany)
Also known as: Ernst August Friedrich Ruska (full name)
Primary fields: Electronics and electrical engineering; physics
Primary invention: Electron microscope

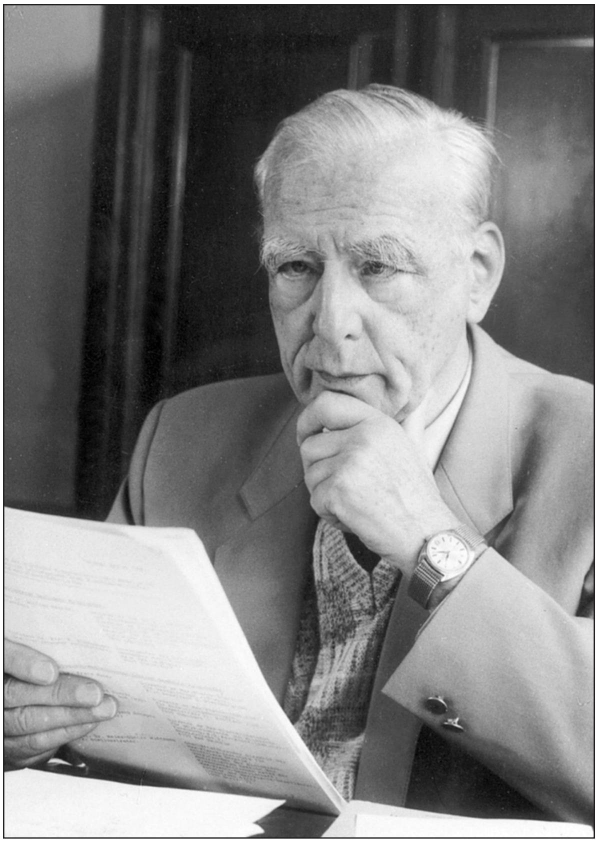
EARLY LIFE

Ernst August Friedrich Ruska (ehrnst OW-goost FREE-drihk ROOS-kah) was the fifth of seven children born to Julius Ruska and Elisabeth Ruska, née Merx. After finishing his early education in the famous university city of Heidelberg, Ruska went in 1925 to the Bavarian capital in Munich, where he studied electronics for two years at the Technical University of Munich. He completed these studies after 1927 at the Technical University in Berlin. His first practical working experience was gained as a research engineer, first at Brown-Boveri and Company in Mannheim, then at Fernseh AG in Berlin, and then with one of the future giants of the emerging electronics industry, Siemens and Halske, also in Berlin. By that time, Siemens and Halske, which had been involved in telegraphy and undersea telegraphic cable communications as well as electric tramway motors in the late nineteenth century, was becoming more and more engaged in the diverse applications of electrical engineering that would make it famous in the twentieth century.

Ruska's studies in Berlin had involved him in research under Adolf Matthias, director of the Institute of High Voltage. Matthias's doctoral students contributed to increasing knowledge of scientific instruments that would be quite relevant to Ruska's later development of the electron microscope, most notably in perfecting early models of the cathode-ray oscilloscope.

LIFE'S WORK

By the time he completed more advanced studies and received his doctoral degree in 1934, Ruska had developed scientific knowledge related to new approaches to microscopy. In a statement presented when he received the Nobel Prize in 1986, he mentioned his interest in 1929 in a contemporary physicist's (Hans Busch's) as yet unproven "theory of the effect of the magnetic field of a coil of wire through which an electric current is passed and which is then used as an electron lens." Within two years, Ruska, collaborating with his colleague Max Knoll, produced a preliminary model of a microscope incorporating the two principles that would become essential to his own ultimate success in breaking free of light-wave technology in microscopy and creating electron-lens technology with unparalleled short focal lengths: emission and radiation.



Ernst Ruska. (©The Nobel Foundation)

In 1933, the year in which he built the first operative electron microscope, Ruska began four years of employment with Fernseh, a German firm pioneering early television technology and photoelectric cells. He then moved to Siemens and Halske, where the Laboratory for Electron Optics was established and produced the first marketable electron microscope, named the Siemens Super Microscope. Siemens and Halske continued to support scientific collaboration on electronic microscopy throughout the period of World War II. Despite Germany's defeat, in 1945 more than thirty scientific institutions were using electron microscopes, a fact that suggests continued scientific exchanges between researchers even during the global conflict.

Four years of reconstruction made it possible for Ruska and his colleagues to begin developing a new generation of electron microscopes. Their work culminated in 1954 when Elmiskop 1 was introduced. Over the next few decades, this perfected electron microscope would become vital to the work of more than one thousand scientific institutions around the world.

After being named to posts at several prestigious institutions—most notably the institute that became the Fritz Haber Institute of the Max Planck Society in Berlin—Ruska was named (within the same institute) director of the Institute for Electron Microscopy. He held this post between 1957 and 1974, the year of his retirement.

In 1986, only two years before his death, Ernst Ruska was awarded one-half of the Nobel Prize in Physics in recognition of his pioneer contribution to electron microscopy. Two other German scientists, Gerg Binnig and Heinrich Rohrer, divided the honor of the other half of the 1986 Nobel Prize for their development of a later, somewhat distinct device of advanced microscopy—the scanning tunneling microscope.

IMPACT

The development of electron microscopy—which led to the technology that produced electron scanning microscopes and scanning tunneling microscopy—opened new horizons for scientific research in a number of

ELECTRON MICROSCOPY

Just as light waves (electromagnetic waves) are reflected to different degrees when they strike different areas of a specimen and can be magnified through an optical lens, electron waves can be reflected from a specimen and directed through a magnifying electrostatic and electromagnetic—as opposed to an optical—lens. The resulting image (essentially the pattern created by reflected electrons) captures and magnifies details thousands of times more minute than images under a light microscope. Typical light microscopy can magnify from five hundred to a thousand times. Improved light microscopy can achieve magnification of about two thousand times. Advanced electronic microscopy magnifies over a million times.

How does an electron microscope work? First, instead of directing a stream of light at a specimen, early electron microscopes used a cathode-ray oscilloscope to emit a barrage of electrons, which were brought into a very narrow focus by passing them through a narrow anode aperture. Electron microscopes are able to record highly detailed patterns created by such a stream of electrons coming into contact with the specimen (some electrons passing through parts of it, others variously deflected). These patterns are magnified by passing the altered electron stream through objective electromagnetic lenses. The image is recorded by exposing a chemically sensitive "photographic sheet" to the emerging electron stream.

It is essential that specimens be contained in a perfect vacuum; the presence of molecules of air anywhere near a specimen can produce inaccuracies in the imaging process. Many specimens require some form of preparatory treatment to enhance the image. This treatment can range from staining to a process called ion beam milling, in which ions of elements such as argon are beamed into the specimen at an angle, thinning the specimen until it becomes transparent to the electron beam.

The electron gun on evolving models of such microscopes (transmission electron microcscopes, or TEMs) used a tungsten filament cathode that marked an improvement over earlier cathode-ray oscilloscope sources for electron beams. Evolving TEM technology, especially once computer software programs could be employed, made it possible to increase levels of resolution. Succeeding generations of high-resolution electron microscopes (HRTEMs) would achieve magnification levels of fifty million times, enough to register the position of atoms within selected specimens in materials such as diamonds, in which individual carbon atoms are separated by only one hundred-millionth of a centimeter.

Beyond the family of TEMs and HRTEMs, a number of other devices emerged in the later twentieth century, including scanning electron microscopes. SEMs produce highly magnified—and nearly three-dimensional—images, not of one specific target but of a succession of areas in the specimen. SEMs obtain very detailed data by recording diverse forms of reaction between electrons in the specimen subareas they strike. Such reactions involve relative degrees of lost energy, manifested in the conversion of electron energy into heat, light (cathodoluminescence), or X rays.

Another category of advanced electron microscopes, called reflection electron microscopes (REMs), uses still another means of tracing electron trajectories by adding technology that can register not the "flying particle" itself but the reflected beam of scattered electrons.

fields. Electron microscopy made it possible to view a significant portion of the minuscule elements composing both organic and inorganic matter. Increased knowledge of the structure of cells and of the basic molecular composition of a large number of inorganic materials held out the promise of unparalleled advances in a variety of scientific and commercial fields. Advances in the field of space technology, for example, have ranged from the design of materials for use in the construction of space vehicles and equipment used to undertake space research to sophisticated analysis of samples of materials brought back to Earth from space missions.

Electron microscopy in several fields connected with medicine and genetic research continues to grow hand in hand with the development of specialized areas (DNA research, for example) that would have been inconceivable without the increased levels of microscopic examination and analysis that began with the work of Ruska and others.

It is important to add that, with the increasing sophistication of computer-driven research laboratories, it has become possible for researchers whose laboratories lack the expensive equipment needed for electron microscopy to benefit from high-resolution images from other laboratories transmitted over the Internet.

—*Byron Cannon*

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See also: Gerd Binnig; James Hillier; Heinrich Rohrer.

JAMES RUSSELL

American physicist

Russell's invention of optical digital recording (ODR) led directly to his development of the digital compact disc storage device, one of the most important technological advances of the twentieth century. The digital compact disc not only revolutionized the way digital media are stored but also transformed the music industry by leading the change from analog to digital recording and reproduction.

Born: February 23, 1931; Bremerton, Washington
Primary fields: Electronics and electrical engineering; music; physics
Primary inventions: Compact disc; optical digital recording

EARLY LIFE

James Russell was born in Bremerton, Washington, in 1931. When he was only six years old, he constructed a remote-controlled battleship, complete with a hidden compartment to store his lunch. Russell demonstrated an early interest in engineering and science and was an avid fan of classical music as a child. He later attended Reed College in Portland, Oregon, where he earned a B.A. in physics in 1953. After graduating, Russell was employed by the General Electric labs in Richland, Washington, where he worked as a physicist.

In his spare time, Russell was a lifelong avid music listener. For much of his life, the only music format available to consumers was the vinyl phonograph record, which was prone to scratches and other damage as a result of the direct contact between the stylus and the record surface necessary to generate sound. Russell was frustrated by the limited audio quality of vinyl records and began experimenting with various design improvements, including using a cactus needle as a stylus. As his part-time experiments continued, Russell began to conceive a music recording system that would be superior to vinyl records and that, in the course of time, would radically transform the music and recording industries.

Russell's ideal system was one that was capable of recording and replaying sounds without requiring physical contact between its parts, the Achilles heel of vinyl records. In order to create such a system, Russell knew that he would need to use light to encode and decode sound. Familiar with digital data recording in the form of punch cards and magnetic tape, Russell determined that, if he could record onto a photosensitive platter, he could represent binary 0's and 1's with dark and light binary pits, or dots, one micron in diameter. A laser could then be used to read the dot patterns of light and dark, which could then be converted by a computer into an electronic signal and made either audible or visible to consumers

THE DIGITAL COMPACT DISC

James Russell was the first person successfully to develop an optical digital recording device, which became the digital compact disc (CD). Russell's compact disc utilized light rather than physical contact to read the data stored on the surface of the device. As his ideas and experiments evolved, Russell eventually created a flat, round disc capable of storing significantly more data than its analog counterparts.

As major corporations purchased licenses to mass produce Russell's compact disc, alterations to the original design were made to accommodate household use. In general, compact discs today are made from nearly pure polycarbonate plastic and measure 1.2 millimeters thick. Data are stored on compact discs as a series of tiny indentations known as pits or dots, which are encoded in a spiral track molded into the top of the polycarbonate layer of the disc. The areas between pits are known as lands. Each pit is approximately 100 nanometers deep by 500 nanometers wide.

A CD player or CD-ROM drive reads by focusing a 780-nanometer-wavelength semiconductor laser through the bottom of the disc's polycarbonate layer. The change in height between the pits and lands results in a difference in intensity in the light reflected from the disc's surface. By measuring the intensity change with a photodiode, the encoded data can be read from the disc.

The pits and lands themselves do not directly represent the zeros and ones of binary data. Instead, non-return-to-zero, inverted (NRZI) encoding is used: A change from pit to land or land to pit indicates a one, while no change indicates a zero. These changes are then decoded by reversing the eight-to-fourteen modulation used in mastering the disc and then reversing the cross-interleaved Reed-Solomon coding, which reveals the raw data stored on the disc.

Russell's goal was to produce a data-storage device that was impervious to the normal wear and tear of repeated use that degraded vinyl records. CDs, however, remain susceptible to damage from both regular use and various environmental factors. Pits are much closer to the label side of a disc, resulting in defects and dirt on the clear side that can be out of focus during playback. Early music CDs were susceptible to "CD rot," or "laser rot," in which the internal reflective layer could degrade. When this occurs, the CD may become unplayable.

Russell's invention of the digital compact disc not only changed the way in which data were encoded for computing but also radically altered the landscape of the music industry, which transitioned from analog to digital recording in order to embrace the benefits of the compact disc. The CD, the CD-ROM, and the closely related DVD are present in tens of millions of homes in the United States and have rendered vinyl records and cassette tapes virtually obsolete.

repeatedly without ever wearing out. Russell immediately understood that if he was able to make the binary code compact enough, he could store a vast amount of information on a very small surface area.

LIFE'S WORK

Immediately following his graduation from Reed College, Russell was hired by General Electric, the private manager of the Atomic Energy Commission's Hanford Nuclear Plant, where his wife, Barbara, worked as a chemist. General Electric made Russell a "designated problem-solver" for its experimental unit, where he would meet with engineers experiencing technical difficulties. During this time, Russell patented several devices that assisted in running Hanford's nuclear reactors and also assisted in the development of complete computer controls for a test reactor. Russell was also among the first to use a keyboard and a color television monitor as the sole interface between computer and operator.

Some of Russell's additional responsibilities included designing and constructing the first electron-beam welder, which applies a beam of high-velocity electrons to fuse materials together. Later, in 1965, Russell joined the Columbus, Ohio-based Battelle Memorial Institute's Pacific Northwest Laboratory in Richland, Washington, to continue his work as a senior scientist.

Battelle let Russell pursue his digital data recording system project, and, after years of work, he finally succeeded in inventing the first digital-to-optical recording-and-playback system, the compact disc (CD), which was patented in 1970. The original design for the compact disc was quite different from the final product. Originally, Russell wanted to produce stereo discs measuring 3 × 5 inches that would fit in a shirt pocket, as well as a punch-card-sized video disc. The final design of the compact disc mimicked the familiar round, flat shape of the vinyl records that had originally inspired Russell. In 1974, Russell was honored with a Research and Development 100 award for his work on optical digital recording.

Under the sponsorship of Battelle, Russell worked on his digital data-recording system throughout the 1970's. He continued to refine the digital compact disc, adapting it to hold any form of data, and by 1980 he had made the first disc player. Like many revolutionary and potentially industry-changing devices, the CD initially found few interested investors. The idea of transforming the computer and music industries by adopting the compact disc as the primary storage medium was perceived to be risky, if not foolhardy, by many industry giants. For years, Russell continued to refine and market his invention, despite the lack of interest. After nearly two decades of unsuccessfully pitching the idea of digital data recording onto compact discs, Sony, Philips, and several other audio companies finally realized the far-reaching implications of Russell's work, purchased licenses for his product, and began mass producing compact discs for consumers.

By 1985, Russell had earned twenty-six patents for compact disc read-only memory (CD-ROM) technology. In 1991, Russell founded his own consulting firm, Ioptics, in Bellevue, Washington, with software entrepreneur Paul Nye. While at Ioptics, Russell continued to invent and patent improvements in optical storage systems, along with bar-code scanners, liquid crystal shutters, and other industrial optical instruments. Despite a multimillion-dollar investment from Microsoft, Ioptics did not remain active, and its patents were sold.

Russell received the Vollum Award for Distinguished Accomplishment in Science and Technology at Reed College's convocation in August, 2000. The Vollum Award is presented to those who exhibit perseverance, a fresh approach to problems and solutions, and creative imagination. Ever the inventor, Russell developed a new, high-speed optical data recorder and player with no moving parts, further reducing the chance of mechanical wear-and-tear or malfunction. Russell earned another eleven patents for this optical random-access memory (ORAM) device, which was initially targeted at handheld computers, cell phones, portable video games, and military devices. Russell hoped that the ORAM would eventually supplant the compact disc as the primary storage medium for a wide variety of information and entertainment devices.

IMPACT

Consumer electronics and developments in computers redefined life and work in the late twentieth century. The adoption of the CD-ROM revolutionized the way computers stored and retrieved data. The device's larger capacity and longevity led it eventually to replace the floppy disk. The music industry was similarly reinvented with the advent of the compact disc, as recording artists and consumers alike embraced the superior quality and durability of digital audio compared to analog.

The CD and the CD-ROM advanced the global transition toward digital technology, through which any information—from still pictures, to text, to music, to video content—can be expressed as a long string of binary code. Today, it is possible to reproduce information not only in rough miniature but also as a series of tiny binary pits. Russell saw how the billions of binary pits used by digital supercomputers could successfully make the transition from the laboratory into the living room.

After large corporations purchased licenses to mass produce compact discs, several modifications were made to Russell's original design in order to facilitate mass marketing and household use. The fact remains, however, that the basic mechanics of the compact discs adopted for use in millions of American homes, as well as the CD-ROMs used in the academic, commercial, medical, and scientific communities, faithfully represent Russell's original system. Russell's early work in optical recording technology formed the physical basis of the defunct videodisc, as well as CD and digital versatile disc (DVD) technologies, which have replaced analog audio and video cassettes in the mass market as a result of their durability and superior playback quality.

—*Sally A. Lasko*

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See also: Willard S. Boyle; Tony Fadell; Gordon Gould; Nick Holonyak, Jr.; Charles Hard Townes.

BURT RUTAN

American aerospace engineer

Rutan was the primary designer of the suborbital rocket plane SpaceShipOne, *which was the first privately funded craft to exceed a height of sixty-two miles, the distance from Earth's surface to the edge of space, twice within two weeks. The feat opened the doors for a commercial space age.*

Born: June 17, 1943; Portland, Oregon
Also known as: Elbert Leander Rutan (full name)
Primary field: Aeronautics and aerospace technology
Primary invention: *SpaceShipOne*

EARLY LIFE

Elbert Leander Rutan, the second of three children, grew up in Dinuba, California. He has said that among the strongest of his childhood memories are the three popular space films that rocketry pioneer Wernher von Braun made in collaboration with the Walt Disney Company between 1955 and 1957 to convince the American public of the need for space exploration. The films, which fascinated Rutan, showed space travel to the Moon, Mars, and beyond as exciting and adventuresome yet somehow mundane.

As youngsters, Burt and his brother, Dick, were interested in building model airplanes. The boys would persuade their mother to drive them up and down the deserted valley roads late at night as they tested the aerodynamics of their model planes by holding the planes out of the car's windows. Burt kept this practice up, although without his mother's assistance, even as he went off to college. Rutan's interest in flight was so great that he had logged his first solo flight before he earned his license to drive an automobile.

Rutan's fascination with aeronautics led him to study aeronautical engineering at California State Polytechnic University. In 1964, he was chosen to represent his university at the Space Technology Summer Institute at the California Institute of Technology (Caltech). Rutan also took coursework in the Aerospace Research Pilot's School at Edwards Air Force Base. He received his degree in 1965 and met Wernher von Braun after accepting an award at a student design competition.

After graduation, Rutan went to work as a test engineer at Edwards Air Force Base in California's Mojave Desert. While working at the base, Rutan narrowly survived a test flight in an F-4 Phantom fighter. Rutan was on the flight to study ways to better control the F-4's notoriously dangerous handling, which was becoming renowned for killing American pilots in Vietnam.

LIFE'S WORK

In 1972, Rutan took a position as director of the Bede Test Center for Bede Aircraft in Kansas. Two years later, he left Bede and returned to the desert, founding his own company, the Rutan Aircraft Factory (RAF), with which he planned to design and sell plans for small, build-it-yourself planes for hobbyists. RAF was underfunded in its early days, so Rutan tested the aerodynamics of his designs by strapping parts to the roof of his station wagon and speeding down deserted roads.

RAF's first design, the Rutan VariViggen, was a two-seat pusher with a canard—a set of wings situated in front of the fuselage ahead of the larger set of wings. This arrangement not only is a staple of Rutan's designs but also makes his vehicles more stable and provides them more lift than a standard plane design. The other essential part of the Rutan design is that most of his vehicles are pushers—that is, the engines are mounted in front of the propellers. This arrangement reduces drag and increases efficiency.

The VariViggen was followed by such successes as the VariEze (and Long-EZ) models, in which RAF pioneered the use of moldless glass-reinforced plastic construction in hobbyists' plane kits. Other well-known RAF creations include the NASA AD-1, Quickie, Defiant, Solitaire, and Catbird. One of Rutan's most famous designs was the Voyager, which Dick Rutan and Jeana Yeager flew nonstop, without refueling, around the world in December of 1986, the first aircraft to accomplish this feat.

In 1982, Rutan formed Scaled Composites, also headquartered in the Mojave, a company that has gone on to be a world leader in aircraft and spaceship design. Scaled is perhaps best known for its work with unmanned aerial vehicles such as the Scarab Model 324 reconnaissance drone for Teledyne Ryan Aeronautical and multimission high-altitude aircraft such as the Proteus. Scaled also developed new ultralight and ultrastrong composite manufacturing processes for military, aerospace, and general aviation. In 1985, Scaled was purchased by Beech Aircraft, which was then sold to Wyman/Gordan in 1989, yet Rutan was retained at chief executive officer.

By the mid-1990's, both Scaled and Rutan had become successful and famous; however, Rutan was discontent. It was while working on the Proteus that Rutan started to draw design sketches of a large plane with a smaller rocket plane strapped to its belly. Then, in 1996, Peter Diamandis, a proponent of civilian space travel, announced a competition called the Ansari X Prize, a $10 million award to the first nongovernment organization to achieve spaceflight and then repeat the flight with the same vehicle within two weeks.

Rutan was contacted by Microsoft cofounder and billionaire Paul Allen, a space enthusiast, who agreed to fund a $20 million program (under the corporate name Mojave Aerospace Ventures, a partnership between Allen and Scaled Composites in their Tier 1 program) to make a serious run for the prize. Though he received the necessary funding, Rutan had some nagging doubts. Scaled had never built a supersonic craft, much less one that could attain Mach 3 (three times the speed of sound). Moreover, Scaled had never launched one aircraft from another, built the types of thrusters needed for spaceflight, or designed the kind of electronic navigational systems needed for spaceflight, not to men-

SpaceShipOne and *SpaceShipTwo*

Burt Rutan is known for designing unusual-looking, durable, and fuel-efficient aircraft and for his own private space program. His *SpaceShipOne*, which cost an estimated $20 million, allowed Rutan to send the first civilian astronaut into space in June 21, 2004. *SpaceShipOne* was designed by Rutan and developed by Scaled Composites. The craft is perhaps best technically described as a manned experimental air-launched suborbital spaceplane that used a hybrid rocket motor that burned a combination of nitrous oxide and rubber. *SpaceShipOne*, like most of Rutan's ideas, started as a drawing on a napkin. Those napkins are on display with *SpaceShipOne* at the Smithsonian National Air and Space Museum. Surprisingly, very little needed to be changed from Rutan's original napkin sketches to the final craft.

Scaled Composites and Sir Richard Branson's Virgin Group are developing *SpaceShipTwo*, which is a part of their Tier 1b program for space tourism. *SpaceShipTwo* will be a larger vehicle, roughly the size of a corporate Gulfstream jet. It will be capable of carrying six passengers and two pilots. Both *SpaceShipTwo* and its launch vehicle will be built from ultralight composite materials. As the launch vehicle for *SpaceShipTwo*, the new incarnation of the White Knight boasts a 140-foot wingspan and a three-fuselage, four-engine design that will allow the pilot to carry *SpaceShipTwo* high into the sky before releasing it. At the moment of release, *SpaceShipTwo* will fire its rocket engines, which will also burn a combination of nitrous oxide and a rubber-based solid fuel to push the craft past the sixty-two-mile mark and into the edge of space. Once there, as with the vehicle's predecessor, the pilot will engage its feathered wing, designed to slow the craft by increasing drag, as *SpaceShipTwo* glides back in for its reentry.

The planned apogee of *SpaceShipTwo* is 110 kilometers (68 miles), some 6 miles higher than the apogee of its predecessor. Despite a fatal accident during a fuel flow test that killed three Scaled employees, Rutan says that *SpaceShipTwo* will be at least as safe as airliners were in the 1920's. If *SpaceShipTwo* is successful, *SpaceShipThree* will likely be an orbital craft.

While some two hundred would-be astronauts have already put down $30 million in deposits with Branson's Virgin Galactic, as of this writing actual passenger flights are not expected to take place for another one to two years.

tion the fact that the company had no experience constructing rocket engines.

Luckily, the breakthroughs came fast. Most, like Rutan's feathered rotating wings on *SpaceShipOne*, which were designed to mitigate the heat of reentry, came from his typical "out-of-the-box" thinking. Although not every step along the path was smooth, enough progress was made so that Virgin Records and Virgin Atlantic Airlines mogul Sir Richard Branson, who was working with Rutan on a project called the GlobalFlyer (a Scaled Composites/Virgin Atlantic craft that would eventually allow pilot Steve Fossett to make the first nonstop, nonrefueled solo flight around the world), caught wind of *SpaceShipOne*. Branson signed on to fund a proposed space airline, flying Scaled Composites vehicles, called Virgin Galactic.

SpaceShipOne was registered with the Federal Aviation Administration as N328KF. The letter *N* is a prefix for a U.S.-registered aircraft; "328KF" was chosen by Scaled to stand for 328 kilo feet (approximately 100 kilometers, or 62 miles), the officially designated distance from Earth's surface to the edge of space. On April 1, 2004, Scaled received the U.S. Department of Transportation's first-ever license issued for suborbital flight. *SpaceShipOne* made history on June 21, 2004, by successfully completing the first privately funded manned civilian spaceflight, soaring to a height of 328,491 feet above the surface of Earth. Then, with successful flights on September 29 and October 4, 2004, Rutan claimed the Ansari X Prize.

IMPACT

Rutan's work has opened new vistas in both the commercial exploration of space and standard aeronautical engineering. *SpaceShipOne* and its launch vehicle, the White Knight (as well as the second-generation versions seen in *SpaceShipTwo*), demonstrated the most efficient and advanced designs in aerospace technology in years. Rutan's use of recycled and recyclable materials as well as the impressive fuel efficiency of his designs set his works decades ahead of those of his contemporaries. In addition, Rutan has shown venture capitalists that investing in commercial space exploration ventures can be profitable.

—B. Keith Murphy

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See also: Wernher von Braun; Hans Joachim Pabst von Ohain; Stanford Ovshinsky; Andrei Nikolayevich Tupolev; Mark Twain; Sir Frank Whittle.

JONAS SALK

American physician and medical researcher

Salk developed the first safe killed-virus polio vaccine. Use of the Salk vaccine has led to the virtual eradication of polio in the United States and in many other countries around the world.

Born: October 28, 1914; New York, New York
Died: June 23, 1995; La Jolla, California
Also known as: Jonas Edward Salk (full name)
Primary field: Medicine and medical technology
Primary invention: Polio vaccine

EARLY LIFE

Jonas Salk was born in the Manhattan borough of New York City in 1914, the first of Dora and Daniel Salk's three sons. Dora and Daniel met while both worked in the garment industry. Although young Jonas loved reading and scholarship, he displayed little interest in science. Dora thought he might become a rabbi. Instead, he told his mother his goal was to go to law school and then become a politician. A gifted student, he attended Townsend Harris High School, which featured an accelerated degree program. Salk graduated at fifteen and immediately enrolled at the City College of New York (CCNY).

Like most colleges, CCNY required all students to take course work outside their proposed degree programs. Salk, who had declared a prelaw major, had to take chemistry. He quickly discovered that he loved science. Salk decided to become a doctor, although he planned to focus on research rather than clinical practice. In 1934, he enrolled at the New York University Medical School.

Salk's first-year courses included microbiology and chemistry. His analytical skills and attention to detail so impressed his professor, R. Keith Cannan, that Cannan persuaded Salk to take a one-year break from medical school to work with him as a research associate. Salk spent the year honing his laboratory skills and learning to breed large amounts of streptococcus bacteria for research. When the year ended, he resumed his medical studies and graduated in 1939. Shortly after graduating and before starting an internship at Mount Sinai Hospital, he married Donna Lindsay, whom he had met in Woods Hole, Massachusetts, the previous summer. It was while engaged to Donna that Salk added Edward as a middle name; from 1939 on, he would be known as Jonas E. Salk.

Jonas Salk. (Courtesy, March of Dimes)

LIFE'S WORK

In 1942, Salk's internship at Mount Sinai ended. The United States had entered World War II a few months earlier, and Salk considered enlisting. He knew the military needed doctors. Before he could sign up, Thomas Francis, the new head of the University of Michigan's Department of Epidemiology, offered Salk a job. Francis had taught at New York University and knew Salk from his days as a medical student. Francis had been impressed then with Salk's research skills. The position Francis offered Salk at the University of Michigan required teaching courses in epidemiology in addition to assisting Francis with influenza virus research. The U.S. military funded the research, which meant that Salk would be exempted from the draft, as the work was deemed necessary to the war effort, and would also know he was helping the troops.

Salk and Francis were determined to develop a killed-virus influenza vaccine. At the time, most researchers believed only a live-virus vaccine could

THE SALK POLIO VACCINE

Jonas Salk's polio vaccine, which was first used for widescale public immunization programs in 1955, is a killed-virus vaccine. Developed from the three strains of poliomyelitis virus responsible for illness in humans, the vaccine was grown using primates as a host and then killed and made harmless to people through the use of formaldehyde.

When Salk began his work with vaccines in the 1940's, most researchers believed that only a live-virus vaccine could produce an effective immune response in the vaccinated patient. Live-virus vaccines are created by passing viruses through hosts such as laboratory mice until the viral strain is sufficiently weakened that it will no longer trigger life-threatening illness. Instead, the weakened virus simply prompts the creation of antibodies resistant to the disease, with the result that exposures to stronger strains of the virus will not cause illness. In rare cases, live-virus vaccines will cause some patients to develop the life-threatening form of the illness. Salk decided that ideal vaccines would be ones that triggered an immune response and subsequent development of antibodies without placing patients at risk of actual illness. His research focused solely on the use of killed viruses.

Salk's initial research projects focused on verifying the major types of polio. By 1947, virologists knew three major types of polio definitely existed: type 1, the most common paralytic type; type 2, a milder form; and type 3, the most lethal. Type 1 apparently occurred in about 85 percent of cases, type 2 in perhaps 12 percent, and type 3 in perhaps 3 percent. After three years of research, Salk and other scientists were confident a vaccine addressing those three types would serve as an effective vaccine against all polio.

In the process of typing the polio virus, Salk and his associates improved on existing methods for growing large amounts of the virus. They built on the work of John Enders, who had first demonstrated a method for growing the virus in a laboratory culture in 1941. Large quantities of the virus would be needed when an effective vaccine was discovered. The live virus was then killed using the chemical formalin, the aqueous solution of formaldehyde.

After Salk tested the vaccine first on himself and then on small groups of volunteers, large-scale field trials were held in 1952. An objective review of the results indicated that the Salk vaccine was effective against all three types of polio. As a result, 1955 vaccination of the general public began. Salk was hailed as a hero by the American public. Polio had been conquered.

One of the drawbacks of the Salk vaccine is that immunity is not conferred with a single dose. The vaccine not only must be injected but also requires booster shots following the initial injection. In the early 1960's, U.S. vaccination programs discontinued use of the Salk vaccine and switched to the Sabin because it could administered as a single oral dose. The Salk vaccine remained in use in Europe.

Public health officials eventually realized that only a killed-virus vaccine such as Salk's could eliminate the disease completely. As the incidence of naturally occurring, or wild, polio declined, the live-virus vaccine increasingly presented an unacceptable risk. Every year, a small percentage of persons given the live-virus vaccine developed what is now known as vaccine-acquired paralytic polio. In the 1990's, the United States switched back to using the Salk vaccine.

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produce an effective immune response in the vaccinated patient. Live-virus vaccines are created by passing viruses through hosts such as laboratory mice until the viral strain is sufficiently attenuated, or weakened, that it will no longer trigger acute, or life-threatening, illness. Instead, the attenuated virus simply prompts the creation of antibodies resistant to the disease, with the result that exposures to stronger strains of the virus will not cause illness. The drawback to live-virus vaccines is that in rare cases they will cause some patients to develop the acute form of the illness. Salk decided that ideal vaccines would be ones that triggered an immune response and subsequent development of antibodies without placing patients at risk of actual illness. His research, first with influenza and later with polio, focused solely on the use of killed viruses.

By 1943, Francis and Salk succeeded in developing an effective killed-virus influenza vaccine. This was a milestone in virology. Salk spent much of the next few years traveling, conducting epidemiological research on influenza outbreaks at military posts in the United States and in Europe. He learned that influenza presents complex challenges in immunization, as multiple subtypes of the virus exist. It would probably never be possible to develop a vaccine that would confer lifelong immunity to all strains of influenza. Instead, researchers would have to track the virus subtypes continually and alter the vaccines annually based on which types appeared most likely to be common in any given year. It was interesting work, but by 1947 Salk felt ready for a change. The University of Pittsburgh offered Salk the opportunity to head his own virology laboratory. Salk accepted. Going to Pittsburgh would give him the rare opportunity to build a laboratory and research staff essentially from scratch rather than taking over an existing research program. It was a daunting challenge, but the potential rewards were great. With a blank slate in front of him, Salk could pick any viral disease to serve as his lab's focus.

Salk decided to focus the lab's research efforts on poliomyelitis, a viral disease that remained poorly understood despite decades of research. Scientists now know that polio is an enteric disease in that the virus enters the body orally and reproduces in the intestinal tract. It is spread through contact with fecal matter. Unlike other enteric diseases such as typhoid and cholera that diminished in frequency as sanitation improved in the twentieth century, however, the incidence of polio paradoxically increased. Even worse, with each new outbreak the numbers of people struck by the most devastating form of the illness also seemed to climb. Thus, it is not surprising that when Salk began his polio research, scientists believed polio was an airborne infection and entered the body through the mucous membranes of the nose. This belief dated back to early research into the polio virus when a researcher tried infecting monkeys with polio and unfortunately chose a species that could not be infected by swallowing the virus, but did acquire the infection when the virus was applied using nasal swabs. Salk, like many other researchers, speculated that polio outbreaks were worse in the summer because the virus traveled with airborne allergens that aggravated its effects.

In 1947, Salk assembled a research team and began working on the polio virus. Using funds from the National Foundation for Infantile Paralysis (NFIP; the organization today known as the March of Dimes), Salk's initial research projects focused on verifying the major types of polio. Since its founding in 1937, the organization had raised millions of dollars to fund research. NFIP grants supported numerous projects, including Salk's later work on a killed-virus vaccine.

By 1947, virologists knew that three major types of polio definitely existed: type 1, the most common paralytic type; type 2, a milder form; and type 3, the most lethal. It is believed that three-fourths or more of persons infected with polio never exhibit symptoms, which meant that people could be active carriers without ever knowing they were spreading the virus. Any effective vaccine would have to be based on all three types. After three years of research, Salk and other scientists were confident that a vaccine addressing those three types would serve as an effective vaccine against all polio.

As Salk switched his focus from typing the virus to developing a vaccine, he found himself in an informal competition with other researchers such as Albert Sabin. Unlike Salk, Sabin thought that the only truly effective vaccine would be one that used an attenuated live virus. He did not believe it was possible to develop a killed-virus vaccine that was simultaneously safe and effective. When the time came for a widespread field trial of the Salk vaccine in 1954, Sabin attempted to block it. The field tests proceeded, and an objective review of the results declared the Salk vaccine safe and effective. The vaccine was approved for use by the general public in 1955.

IMPACT

Salk's work with a killed-virus vaccine for polio helped eliminate polio as a devastating disease in the United States. In addition, although U.S. immunization programs switched to the Sabin live-virus vaccine after it was introduced in 1959 because it was easier and cheaper to administer, it eventually became clear that only a killed-virus vaccine such as Salk's could eliminate the disease completely. The U.S. resumed using the Salk vaccine in the 1990's.

—*Nancy Farm Mannikko*

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See also: Robert Charles Gallo; Edward Jenner; Louis Pasteur.

HENRY THOMAS SAMPSON

American nuclear engineer

Sampson designed innovative methods for preparing propellants for effective rocket and missile performance. He also developed an improved device for producing electricity from nuclear radiation. His inventions were appropriated for aerospace, military, and industrial applications.

Born: April 22, 1934; Jackson, Mississippi
Primary fields: Aeronautics and aerospace technology; electronics and electrical engineering
Primary inventions: Gamma-electric cell; propellant bonding process

EARLY LIFE

Henry Thomas Sampson was born on April 22, 1934, in Jackson, Mississippi, to Henry and Esther (Ellis) Sampson. His father, who earned a master's degree from the University of Chicago the year before Sampson's birth, was a mathematics professor and academic dean at Jackson College (later Jackson State University). In 1938, Sampson's family moved to Georgia when his father was appointed junior division dean at Savannah State College. In 1942, Sampson returned to Jackson, where Jackson College administrators named his father an executive dean. Sampson's mother, Jackson's first African American social worker, also served as that city's Head Start program executive director. His parents were community and church leaders and involved their children in related activities. Jackson State University later named its library and a mathematics award in honor of Sampson's father.

Sampson and his brother John attended segregated schools. Enthusiastic about learning, Sampson enjoyed trying to understand the principles and components necessary for mechanisms to function. On Saturdays, Sampson's godfather and neighbor, Mr. Patterson, took the brothers to matinees at African American theaters in Jackson. For six cents, Sampson delighted in watching a double feature with casts made up entirely of African American actors. Sampson realized that these independent films presented African Americans realistically and not as demeaning stereotypes often portrayed in mainstream Hollywood movies.

After Sampson graduated from Lanier High School in 1951, he enrolled in his father's alma mater, Morehouse College, in Atlanta, Georgia. There he focused on chemistry studies for two years. Interested in an engineering career, he transferred to Purdue University in West Lafayette, Indiana, and completed a bachelor's degree in chemical engineering in 1956. He sought employment with oil industries in Mississippi but was rejected by employers who discriminated against minorities. Sampson secured a civil service position at the U.S. Naval Weapons Center in China Lake, California, and traveled west by train from Jackson to begin his professional career.

LIFE'S WORK

At the Naval Weapons Center, Sampson utilized his chemical engineering skills and knowledge to conduct research for the Navy. He specialized in devising methods for developing solid propellants for rockets and case bonding materials for positioning those propellants in rocket motors. In addition to work, Sampson enrolled in graduate school at the University of California, Los Angeles (UCLA). He married Elizabeth A. Boland on February 26, 1961, in Clark County, Nevada, and their first child, Henry Thomas Sampson III, was born that year. They later had a second son, Martin Todd. During 1961, Sampson completed a master of science degree in engineering, writing a thesis titled "The Analysis of the Effects of Grain Defects on Solid Propellant Rocket Engines."

In October, 1961, Sampson received his first U.S. patent, number 3,212,256, for his invention "Case Bonding System for Cast Composite Propellants," assigning rights to the U.S. government to produce and use that invention. On February 2, 1962, Sampson filed for his second patent, for a "Process for Case Bonding Cast Composite Propellant Grains," which was issued eleven years later in May, 1973 (number 3,734,982), and also assigned to the U.S. government, for use directed by the secretary of the Navy. This invention described techniques for creating liners for securing propellant inside rocket motors or casings so that the propellant would withstand vibrations and extreme temperatures.

Sampson aspired to earn a doctorate in nuclear engineering, and he applied to the University of Illinois because it had a powerful nuclear reactor that suited his research interests. Leaving California in 1962, Sampson worked closely with Dr. George Hunter Miley, a nuclear engineering professor who advised him at Illinois. While attending graduate school, Sampson received a U.S. Navy Educational Fellowship (1962-1964) and an Atomic Energy Commission fellowship (1964-1967).

While attending the University of Illinois, Sampson was granted a patent for a "Binder System for Propellants and Explosives," in July, 1964. The patent outlined methods for making binder compositions from castor oil and several chemical compounds. It described a procedure for lining fuel tanks in rockets with plastics and adhesives and filling them with liquid fuel that solidified and attached to the liner when heated. This strategy prevented liner shrinkage, which might expose propellants to oxygen and increase pressure inside the tanks.

By 1965, Sampson had completed sufficient course work and original laboratory investigations at the University of Illinois to qualify for a master of science degree in nuclear engineering. He continued his studies, focusing on nuclear physics and energy research with Miley, and in 1967 he became one of the first African Americans to earn a Ph.D. in nuclear engineering. His dissertation was titled "A Theoretical and Experimental Analysis of the Gamma-Electric Cell." Sampson and Miley described their work in a November, 1966, *Transactions of the American Nuclear Society* report, "High Voltage Gamma-Electric Cell Theory and Experiment." They also published an article, "High Voltage Gamma-Electric Cell Operation," in *Nuclear Applications* in 1968. In July, 1968, the pair filed for a patent for their gamma-electric cell (GEC), which was issued three years later.

Impressed with Sampson's accomplishments, administrators at the Aerospace Corporation in El Segundo, California, offered him a technical staff position. Returning to California in 1967, Sampson worked as a project engineer, contributing to the design and simulation of electrical power systems for spacecraft. Sampson shared his findings in presentations and publications. He belonged to the American Nuclear Society and the American Institute of Aeronautics and Astronautics. Starting in 1976, Sampson served on an advisory commission on nuclear engineering. In 1981, he was promoted to director of planning and operations for Aerospace Corporation's Space Test Program and continued this work until his retirement in the early twenty-first century.

After Sampson and his wife divorced in June, 1973, he began researching African American films by reading contemporary reviews in African American periodicals, interviewing African American filmmakers, and consulting archives and private collections. He wrote *Blacks in Black and White: A Source Book on Black Films* (1977), which inspired interest in

GAMMA-ELECTRIC CELL

In the 1960's, Henry Thomas Sampson endeavored to improve existing electric cell technology created to produce electricity from radiation. Since the early twentieth century, scientists had noticed electrical charges associated with radium and pursued investigations to derive and store energy from radiation. To avoid structural flaws, Sampson studied electric cells designed by nuclear engineers and physicists, particularly Bernhard Gross. Sampson consulted Gross's 1964 U.S. patent, "Method and Apparatus for Measuring the Dosage of X-Rays and Gamma Rays" (number 3,122,640), which described an electric cell stimulated by gamma rays to create electrical energy. Sampson also read technical articles in periodicals such as *Nucleonics*.

Sampson and his mentor George Hunter Miley received a patent for their gamma-electric cell (GEC) invention in July, 1971 (number 3,591,860). Sampson constructed the GEC by building a central metal collector, usually made from tungsten or lead. He placed other collectors adjacent to the central collector. Unlike previous cell designers, Sampson encased the collectors with a substance—usually polystyrene, silicon, or epoxy—with dielectric properties, allowing electrical currents to pass through it. He waited for trapped gases to dissipate after he encapsulated the collector and then heated the materials at temperatures ranging from 40° to 60° Celsius (104°-140° Fahrenheit) for durations of several days or weeks. This curing process prevented surface charges (which diverted electricity) from forming.

When gamma-ray radiation contacted the dielectric material, that layer dispersed electrons in a process known as Compton scattering, and voltage accumulated in the collectors. Compared to other electric cells, which leaked voltage, Sampson's GEC produced abundant electricity. This voltage supplemented electrical power routinely provided by nuclear reactors to improve services to consumers and ensure more consistent power supplies. Sampson stated that nuclear reactor shields could use his invention to secure additional energy resources by gathering electricity from gamma-ray residue directed there. He also stressed that his GEC technology could be used to measure radiation in nuclear reactors and detect its presence elsewhere to protect communities vulnerable to exposure to that hazard.

Sampson's GEC influenced other inventors who referenced his patent in their applications in the 1980's and 1990's. Their inventions focused on energy generation or addressed safety issues associated with handling and discarding radiation to protect people, animals, and the environment.

African American film scholarship. Sampson published four additional books about African American entertainment that combined his technical and cultural interests: *Blacks in Blackface: A Source Book on Early Black Musical Shows* (1980), *The Ghost Walks: A Chronological History of Blacks in Show Business, 1865-1910* (1988), *That's Enough, Folks: Black Images in Animated Cartoons, 1900-1960* (1998), and *Swingin' on the Ether Waves: A Chronological History of African Americans in Radio and Television Broadcasting, 1925-1955* (2005). Sampson's expertise on the subject resulted in his consulting and lecturing on African American films for documentaries and educational programs. In 2007, he married Laura Howzell Young, a music educator and author.

IMPACT

Sampson's inventions fulfilled energy, transportation, and communications needs for commercial, domestic, and military uses. His early inventions describing how to create solid rocket propellants and containers for those fuels helped minimize explosion risks and reduce costs associated with rocketry and propellant losses. His propellant bonding process improved safety for individuals using rockets and missiles. The Navy applied the process to submarine-based missiles in order to prevent those devices from prematurely detonating and killing crews and damaging crafts. His techniques were appropriated to aerospace engineering, particularly rockets launching spacecraft, including the space shuttle, to reduce propellant-related accidents. The full impact of Sampson's propellant-related inventions is unclear because of the secrecy associated with their use.

Sampson's gamma-electric cell proved useful as a radiation detector. Nuclear reactor employees used the GEC to monitor radiation levels. Government personnel appropriated Sampson's GEC to assess how much radiation resulted from nuclear weapons tests, then used it to transform dangerous radiation into benign forms of energy.

Other than patent references, public recognition for Sampson's accomplishments was limited to his peers and employer. The Aerospace Corporation presented Sampson its Black Image Award in 1982. The next year, the Los Angeles Council of Black Professional Engineers honored Sampson with the Blacks in Engineering, Applied Science, and Education Award.

—*Elizabeth D. Schafer*

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See also: Wernher von Braun; Robert H. Goddard; Konstantin Tsiolkovsky.

SANTORIO SANTORIO

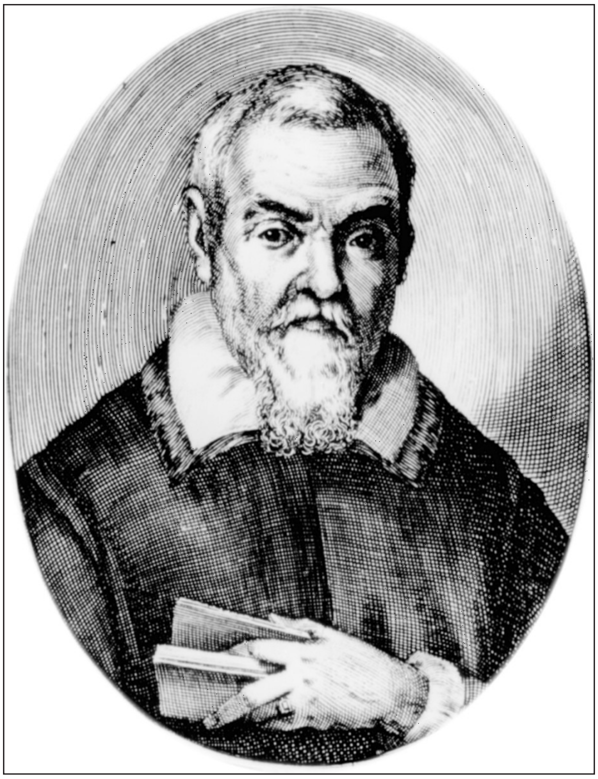
Italian physician

Santorio invented or improved several basic medical instruments, most notably the clinical thermometer. One of the earliest medical researchers to quantify data, he also studied the effects of respiration, environmental temperature, body temperature, and body weight on health and metabolism.

Born: March 26 or 29, 1561; Capodistria, Republic of Venice (now Koper, Slovenia)
Died: February 22 or March 6, 1636; Venice (now in Italy)
Also known as: Sanctorius Sanctorius
Primary field: Medicine and medical technology
Primary invention: Air and clinical thermometers

EARLY LIFE

Santorio Santorio was the son of a Venetian nobleman, Antonio Santorio, and his wife, Elisabetta, née Cordona, also from a noble family. His father served the Venetian Republic in military and diplomatic affairs. As the child of an aristocratic government official, Santorio received the best available education and established lifelong connections with wealthy citizens, such as the Morosini family, that would later provide patronage support for his work. After a classical education with tutors in Capodistria and Venice, he entered the University of Padua in 1575. There he studied philosophy, literature, and medicine, receiving his medical degree in 1582. Among his professors was the anatomist Girolamo Fabrizio d'Aquapendente, known as Hieronymus Fabricius.



Santorio Santorio. (Library of Congress)

What Santorio did between 1582 and 1587 is obscure, but from 1587 to 1599 he was the court physician to a Croatian nobleman, probably of the Zrinski family. In 1599, Santorio established a private medical practice in Venice along the Hippocratic and Galenic lines that were then standard. Through Andrea Morosini he became friends with the physicist Galileo and several other prominent scientists, including Galileo's student at the University of Padua, Giovanni Francesco Sagredo; the cryptographer Giambattista della Porta; the prominent churchman Fra Paolo Sarpi; and Fabrizio. This circle would prove fruitful not only for the scientific endeavors of each of its members but also for their political safety against the Inquisition. Sarpi represented relatively liberal Venice in its conflict with the papacy of Paul V. Fabrizio and Santorio performed the surgery that saved Sarpi's life after an assassination attempt by the pope's agents on October 5, 1607.

LIFE'S WORK

Santorio's prestige steadily increased in Venice. The Venetian senate appointed him in 1611 to a six-year term as professor of theoretical medicine at the University of Padua. In 1617, his appointment was renewed. After retiring from this professorship in 1624, retaining both his academic title and his full salary, he spent the rest of his life in Venice, continuing to see patients until his death, serving as president of the Venetian College of Physicians, and directing local efforts against the bubonic plague in 1630.

At Padua, Santorio participated equally in all three aspects of the medical profession: patient care, scientific research, and training new physicians. At the same time that he continued his clinical practice in Venice, he conducted the research on thermometry, metabolism, and measurement that would make him famous. His focus was on creating better instrumentation. Among his in-

Air and Clinical Thermometers

The need to measure heat in various contexts was gradually recognized during the Renaissance. Accordingly, the thermometer was not invented all at once, but several European inventors from 1593 to 1724 developed different thermometers for different purposes. The first of these inventors was Galileo, who between 1593 and 1596 invented an uncalibrated device to display visually the heat of air. This was not the well-known "Galileo thermometer," which uses rising and falling glass balls inside a sealed glass column of liquid to display ambient air temperature. That device was actually invented about half a century later, probably by the German Jesuit scientist Athanasius Kircher, whose work was based on Galileo's principles of liquid density and buoyancy.

Galileo's air thermometer was really a thermoscope, not a true thermometer, because, not being scaled, it only represented the temperature but did not measure it. Santorio Santorio saw that the greatest improvement to this instrument would be calibration. After making several design changes and adding a scale to create the first genuine air thermometer, Santorio used this knowledge to invent the clinical thermometer, which he introduced in 1612. His prototypes of a calibrated device to measure body heat were not entirely new instruments but rather variations of his air thermometer.

In Rome in 1611, Italian mathematician and engineer Bartolomeo Telioux wrote a Latin manuscript called *Mathematica maravigliosa*, which included the first known illustration of a calibrated air thermometer. Telioux attributed the instrument to Santorio and depicted it as two volumetric flasks, the thin neck of one inverted inside the thick neck of the other. A column of liquid rested normally around the midpoint of the two necks. A 48-degree scale was etched in eight divisions on the outer neck.

Santorio's 1612 book, *Commentaria in artem medicinalem Galeni* (commentary on Galen's art of medicine), contained the earliest printed mention of any thermometer, his own air thermometer. In 1625, his *Commentaria in primam fen primi libri canonis Avicennae* (commentary on the first section of the first book of the canon of Avicenna) contained both the first mention and the first four illustrations of clinical thermometers. The first of these woodcuts represents an uncalibrated Florence flask with its long, thin neck inverted in water. The instrument would detect body temperature when the patient grasped the body of the flask. Temperature was recorded by sliding circles of thread up and down the neck. The second woodcut shows an oral thermometer consisting of a calibrated flask with its tiny bulb to be placed inside the patient's mouth. Its amazingly long neck, which remained outside the body, increased the accuracy of its scale, and the thermometer's four switchback curves prevented it from being unwieldy. The third illustration shows a similar instrument with a larger bulb so that the patient would take it in the hand, not the mouth. The last woodcut depicts Santorio's third calibrated clinical thermometer, the least accurate, which provided for the patient to exhale into a funnel.

Developers of the calibrated air thermometer subsequent to Santorio included English physician Robert Fludd about 1615, Dutch glassblower Cornelis Drebbel before 1625, and German physicist Otto von Guericke about 1660. French Jesuit and mathematician Jean Leuréchon coined the term *thermomètre* (thermometer) from the Greek *thermos* (hot) and *metron* (measure) in 1624 to distinguish it from the thermoscope. French physician Jean Rey invented the liquid thermometer between 1630 and 1632. It lacked an airtight seal to avoid the influence of barometric pressure. Ferdinando II de' Medici, grand duke of Tuscany, developed the sealed liquid thermometer between 1641 and 1654. The modern thermometer was considered complete when the German physicist Daniel Gabriel Fahrenheit introduced the sealed alcohol thermometer in 1709, the sealed mercury thermometer in 1714, and the Fahrenheit scale in 1724.

ventions or improvements to existing inventions were gauges to measure the speed of wind and water; a hygrometer; a "pulsilogium," which used a pendulum to measure the human pulse rate; and several kinds of thermometers, syringes, and therapeutic beds and chairs. His aim was always precision, unusual for his time.

As a medical philosopher, Santorio was an iatromechanist. In the sixteenth and seventeenth centuries, two rival theories of medicine, iatrochemism and iatromechanism, sought to reduce medicine and physiology to other, presumably simpler, sciences. Iatrochemism was the idea that medical phenomena are essentially chemical or pharmacological, and that medicine accordingly could be reduced to chemistry, alchemy, and the study of drugs and mineral and herbal remedies. Iatromechanism, on the other hand, claimed that medical phenomena are essentially physical or mechanical, which would reduce medicine to physics, mechanics, and mathematics. It would be an oversimplification to say that iatrochemism advocated qualitative science while iatromechanism advocated quantitative. Nevertheless, many iatromechanists, including Santorio, made significant advances in quantitative study.

Santorio was particularly interested in the effects of changes in body heat on health and disease. He believed that reliably quantifying body heat and measuring its changes could help both diagnosis and subsequent therapy. The circulation of the blood was not yet understood; William Harvey, another University of Padua medical alumnus, would not publish his findings in this area until 1628. Still, Santorio suspected that a relation existed among respiration, body heat, and evaporation that would somehow involve the blood. He reasoned that accurately measuring small changes in body heat would facilitate the study of this relation. Because the instruments necessary to detect such small changes did not exist, Santorio invented them. In 1602, he published *Methodus vitandorum errorum omnium qui in arte medica contiguunt* (on the method to follow to avoid errors in the medical art), which presented his first quantitative innovations and developed specific protocols for bringing greater accuracy into medicine and physiology.

IMPACT

In an era when medical thought and research were typically speculative, qualitative, or even subjective, Santorio was a pioneer of meticulous observation and rigorous quantification. He was passionate about quantification. He believed in the close relationship between mathematics and science, which was controversial at the time, and that careful measuring was the key to scientific progress. For thirty years, he regularly weighed himself, everything he ate and drank, and everything he excreted. From these data, having noted that the weights of what he consumed and what he knowingly excreted did not match, even when considering changes in his body weight, he inferred the existence of an invisible excretion, "insensible perspiration," to account for the difference. He published the results of these experiments in 1614 as *De statica medicina* (on medical measurement). This book was widely read by physicians and stayed in print until 1784. Many of its physiological conclusions were verified in the eighteenth and nineteenth centuries and earned him distinction as a founder of basal metabolic research.

Santorio's introduction of the clinical thermometer into the medical arsenal aided not only direct patient care but also the physiological research that is the basis of patient care. His instruments and methods remained useful until the end of the eighteenth century and especially enabled progress in cardiovascular and respiratory physiology. They led in the 1660's to iatromechanists disproving Galen's belief that the function of the heart was to heat the body and the function of the lungs was to cool it, with their interaction striking a balance that, in health, would ensure the best possible body temperature. Giovanni Alfonso Borelli extended Santorio's research on respiration and evaporation to account for muscular movement and function according to iatromechanistic principles.

—*Eric v.d. Luft*

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See also: Daniel Gabriel Fahrenheit; Galileo.

THOMAS SAVERY

English engineer

Savery created and patented the first steam engine to power drainage pipes, especially in mines. Although his device was not successful in mines, his demonstration of the power of steam led to improved steam engines by such inventors as Thomas Newcomen and James Watt.

Born: c. 1650; Shilstone, Devonshire, England
Died: May, 1715; London, England
Primary field: Mechanical engineering
Primary invention: Savery pump

EARLY LIFE

Thomas Savery was born about 1650, a son of one Richard Savery and a grandson of Christopher Savery. Thomas's family were substantial landowners in the vicinity of Modbury in the county of Devonshire, England. Savery trained as a military engineer, rising in the military to the level of trench master. His early career, however, was spent devising machines or tools useful to the military, including a device to polish glass that he patented in 1696. He also produced a mechanism that could propel small boats in calm waters by using a capstan attached to two waterwheels. This latter device won him the admiration of the reigning monarch of England, William III, though it never was adopted by the British navy. Savery published in 1698 a description of his rowing mechanism in a pamphlet titled *Navigation Improved.*

LIFE'S WORK

Savery's work marked a change in the attitudes then prevailing about the world. There had long been a considerable interest in Earth and its position relative to the stars, and the work of Nicolaus Copernicus and others had made people aware that Earth was just one planet among a considerable body of stars and constellations, leading people to focus more particularly on the status of Earth itself and the observable features of its position in the cosmos. This in turn led to the realization that Earth was surrounded by an atmosphere, and that the atmosphere had weight. Without the atmosphere, a vacuum would exist, and that vacuum could be exploited as a force.

The first person to tap into the power of the vacuum was Otto von Guericke, an official of the German city of Magdeburg. In 1650, he constructed two hemispheres that he sealed together and then revealed that they could not be readily pulled apart if the air inside them had been removed. Robert Boyle, an Englishman and the seventh son of the earl of Cork, traveled widely on the Continent and learned of Guericke's work. When he returned home, he applied the principles used by Guericke and built a rudimentary pump that he demonstrated to the Royal Society, a learned society established by the restored English monarch, Charles II, in the early 1660's. In the 1690's, a collaborator of Boyle, a Frenchman named Denis Papin, constructed a cylinder and piston device that demonstrated the basic concept used by Savery, but he did not pursue this idea further.

Savery picked up on the concept (his military connections enabled him to make himself familiar with the ideas circulating in the Royal Society) and decided to apply it to the practical problem facing England at that time—a shortage of wood for fuel. This shortage had led to the exploitation of coal, and there were many mines in the England of that day that had been tapped into for several centuries. However, by the late seventeenth century, the easy deposits had already been mined, and many miners went down one hundred feet or more to tap into the coal. At that depth, many mines tended to fill with water, so what was needed was a way to pump out the water. Savery developed a water pump that heated water in a boiler that, when cooled, pulled out the steam in an adjacent, connected cylinder, leaving a vacuum. He demonstrated a prototype to the Royal Society and applied for a patent, which was granted in July of 1698. The original patent was for just fourteen years, but it was extended for another twenty-one years by an act of Parliament.

Savery's patent was for a "new Invention for Raiseing of Water and occasioning Motion to all Sorts of Mill Work by the Impellent Force of Fire," and this description was generally held to mean all steam engines, so that it precluded other inventions that used the force of steam to create a vacuum, the basic principle at stake. Savery, who seems in many ways to have been more a promoter than a scientific luminary, then wrote a pamphlet, titled *The Miner's Friend*, which he published in 1701. The pamphlet makes clear that his intended market was the mining industry, which in those days meant chiefly the coal-mining industry, although the mining of tin in southwest England suffered from the same problems.

In 1702, Savery set up a workshop in London where he displayed a working example of his pump with the intent of demonstrating it to potential purchasers. In fact, the pump in action revealed a number of defects. The

THE SAVERY PUMP

Thomas Savery's pump consisted of a containing cylinder with a piston inside it. Water was heated in an adjoining boiler, and the steam produced was fed into the cylinder, causing the piston to rise. The cylinder was then cooled, condensing the steam back to water, which fell back into the boiler, leaving a vacuum in the cylinder. The vacuum pulled water up into a pipe connected to the cylinder. It was intended that this vacuum be used to bring up water from the bottom of coal mines.

However, the application had limited value, as it soon became clear that the force of the atmosphere would pull up water only thirty-two feet in a contained pipe. Dual pipes could double that figure, but they were not enough to pump water out of mines that were often one hundred feet deep. Moreover, it was soon discovered that the Savery pump would function better if placed at the bottom of the mine, which proved to be impractical.

The practical difficulties encountered ensured that Savery's pump would not find much use in the coal-mining industry, for which it was intended. It did, however, find a number of applications on the estates of large landowners, and Savery's own social status helped to find it a market there. It was only the significantly modified version designed by Thomas Newcomen that found numerous industrial applications.

Nevertheless, the Savery pump represents the first known attempt to apply steam power to endeavors that had previously relied on human power or animal power (except in the rare cases in which wind or waterpower could be so used). It led directly to the inventions of Newcomen and, much later, James Watt. The concept of steam power was seized upon by other innovators and modified so as to be effective where Savery's machine was not. In particular, advances in metallurgical techniques were essential so that engines could be built that could withstand the great power of steam without disintegrating into their component parts. As others worked on this problem, the limitations of the atmospheric pump became clearer and inspired work that used elevated steam force to accomplish what the atmospheric pump could not.

The Savery pump was also significant in that Savery's patent made it impossible for anyone to produce a steam engine until the patent expired in 1733. That circumstance compelled Newcomen to work closely with Savery during the latter's lifetime and constrained him even after Savery's death while the patent was controlled by a trust.

skills of the metalworkers of the time made its construction difficult, for it relied on an airtight seal that was hard to produce. Common practice used copper in the construction of devices whose various components were attached to one another with solder, and these devices tended to blow apart under the pressures needed to produce a vacuum. The parts were constructed separately, and creating seals that would ensure a vacuum when the parts were joined together proved difficult.

Savery folded the London office after a few years, having made few sales (and apparently none to proprietors of coal mines), but continued on with his military career. By this time, he had been promoted to captain, and he was commonly referred to at that time as Captain Savery. In 1705, he received a patronage appointment from the government to a body dedicated to caring for naval veterans. In 1706, he was elected a fellow of the Royal Society, and he continued to produce a variety of inventions, including a kind of hand bellows that could elevate the temperature of a fire used to make metals pliable, for which he received another patent. His connection with the royal family led once again to a special appointment in 1713, when he became surveyor to the waterworks at Hampton Court, a royal palace. There his professional expertise could be put to good use. He died in London shortly thereafter.

IMPACT

Although Savery's original patent was for only fourteen years, an act of Parliament passed on April 25, 1699, extended the patent for a further twenty-one years. This patent history explains in part why Savery's invention was so important historically. Further work based on Savery's concept was done during his lifetime and in the years immediately after by Thomas Newcomen (1663-1729), who worked under Savery's patent, which expired in 1733. Newcomen's steam engine would become widely used throughout the eighteenth century.

Savery demonstrated that steam could be used to create power other than that generated by water, wind, or animals. In so doing, Savery inaugurated more than two centuries of the use of steam power to activate machines, most notably the steam engines that would run railroads, steamships, and an enormous list of industrial enterprises. Without the string of inventions, each built upon its predecessor, that turned steam into such a potent force, the Industrial Revolution would not have happened. The modern world owes much to Thomas Savery.

—*Nancy M. Gordon*

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See also: William Murdock; Thomas Newcomen; James Watt.

ARTHUR L. SCHAWLOW

American physicist

Schawlow's numerous inventions and improvements to laser spectroscopy were rewarded with a Nobel Prize in Physics and revolutionized laser technology. They greatly increased both the types and the applications of lasers across a wide array of disciplines and arenas.

Born: May 5, 1921; Mount Vernon, New York
Died: April 28, 1999; Stanford, California
Also known as: Arthur Leonard Schawlow (full name)
Primary field: Physics
Primary invention: Laser spectroscopy

EARLY LIFE

Arthur Leonard Schawlow (SHAW-loh) was born in New York to a Canadian mother and a Latvian father. His father was an insurance salesman with a keen interest in mathematics. He moved with his family to Canada at age three and spent his entire youth there, although he remained an American citizen. Precocious as a child, Schawlow devoured *The Children's Encyclopedia* (1908; also known as *The Book of Knowledge*, 1911-1912) and books from the local library on aviation, electronics, and radios. He played with radios, learned to play clarinet, and devoted some energy to the Boy Scouts.

Schawlow completed high school in 1937, having just turned sixteen. He took the required Ontario provincial examinations and scored well enough to be offered a scholarship to attend the University of Toronto to study mathematics and physics, which he thought close enough to his primary interest, radio engineering. He graduated in 1941 with a B.A. in physics. By then, Canada had been engaged in World War II for two years. The final months of his bachelor's program consisted exclusively of working on government projects related to the war effort, rather than taking courses, which had been canceled.

Schawlow's master's program followed a similar pattern. He earned an M.A. in physics in 1942 based on some work he did on a centrifugal battery related to proximity fuses in artillery shells, despite the fact that superior work on this approach was already being conducted in the United States. Schawlow spent the next two years at the university teaching basic physics courses to military recruits. He then joined Research Enterprises, working to improve microwave antennae for radar for the remainder of the war.

Schawlow returned to the University of Toronto in 1945 in response to an offer of continuing scholarship support, as his family was of limited means. He earned a Ph.D. in physics in 1949, specializing in spectroscopy. His dissertation, written under Professor Malcolm F. Crawford, was titled "Nuclear Properties from Hyperfine Structures." He made it a practice throughout his doctoral work to scan weekly the entire set of new physics and engineering journals received by the university's library. In that way, Schawlow both developed and maintained an interest across the scope of physics that would prove useful throughout his career. He also played clarinet in the Delta Jazz Band and started collecting jazz records, a passion throughout his life: Any visitor to his scientific laboratories over the years could attest to the jazz music frequently played there.

LIFE'S WORK

While still a doctoral student, Schawlow heard a presentation by Nobel laureate Isidor Isaac Rabi of Columbia University at the Canadian Association of Physicists meeting in Ottawa. As a result of that presentation, he wrote to Rabi, as well as scholars at a few other American universities, seeking employment. Rabi suggested he apply for a Carbide and Carbon Chemicals Corporation postdoctoral fellowship to work under Charles Hard Townes at Columbia. Schawlow applied and was accepted, despite knowing nothing about the work Townes was doing.

Arthur L. Schawlow. (©The Nobel Foundation)

Thus began a long and creative relationship with the older Townes, who became Schawlow's brother-in-law in 1951 after his wife introduced Schawlow to Townes's younger sister Aurelia. The physics department at Columbia was at the center of physics work globally at this point, with eight current or future Nobel laureates emerging from the program. The illustrious faculty, engaging graduate students, ample facilities, and visits from world-renowned physicists produced a stimulating atmosphere in which Schawlow became familiar with many additional areas of physics and developed his ability to focus on conceptual problems.

When Schawlow's fellowship ended, it was impossible for him to take a job at Columbia, because his brother-in-law was the department chair. His wife wished to stay in New York as a musician and conductor, however, so Schawlow accepted a position as a physicist at Bell Telephone Laboratories, where Townes had previously worked. He worked at Bell Labs from 1951 to 1961, focusing on superconductivity and issues related to nuclear quadrupole resonance, but without significant results. The corporate laboratory environment, with its relative isolation, did not appeal much to Schawlow, although he ultimately found effective ways to reach out to others for assistance with his ideas. Every weekend found him continuing his collaboration with Townes on a substantial book, *Microwave Spectroscopy*, which they published in 1955 to critical acclaim.

Meanwhile, Townes, James P. Gordon, and Herbert Zeiger built a maser (an acronym for "microwave amplification by stimulated emission of radiation") in 1954, following up on an idea that Townes had had as early as 1951. Townes and Schawlow began to think about how the principals of a maser might be applied to visible light. They published a famous paper, "Infrared and Optical Masers" (1958), in *Physical Review*, summarizing their theoretical progress. This paper became the basis for a revolution in optics for visible energy (light).

A maser is a device that works at the molecular level to cause atoms to vibrate back and forth (oscillate), creating an energy difference between their excited and ground states. Focusing the energy (radiation) from this difference results in amplification of the beam. The Townes and Schawlow continued their "normal" work while tinkering further with their ideas concerning visible light. Townes selected metal potassium as a suitable material that yielded a light-emitting vapor when excited. Schawlow suggested using a pair of mirrors at the end of the tube to focus the resultant light into a weak beam.

The pair filed a patent application during this period, while Townes's questions to Columbia graduate student Gordon Gould resulted in Gould pursuing his own ideas independently and also filing several patent applications. Townes and Schawlow obtained the first patent for a laser ("light amplification by stimulated emission of radiation," a term coined by Gould at a 1959 conference that Schawlow chaired). Legal battles over many years, however, resulted in a 1977 ruling that awarded Gould millions of dollars in laser royalties on the basis of four patents, while Townes and Schawlow collected none. However, Townes rather than Gould won a Nobel Prize in Physics in 1964 for his work on the laser. Schawlow would wait many more years for his own Nobel Prize.

Schawlow had an intuitive hunch that the best way to create an excitation, amplification, and concentration of the energy of visible light might be to exploit the optical properties and spectra of solids. He was especially drawn to rubies because of their basic properties and the abundance of samples at Bell Labs. A false lead from a chemist at Bell Labs, however, led Schawlow down a wrong path. Meanwhile, Theodore Harold Maiman at the Hughes Research Laboratories succeeded in generating a ruby-laser pulsed light on May 16, 1960. Schawlow, upon learning of Maiman's feat, quickly replicated it and published the first detailed report on laser experiments.

Schawlow desired to return to the university environment and was eager to work with graduate students. He received offers from a number of institutions and chose Stanford University in 1961, both for its research opportunities and because of a special program available to the Schawlows' autistic son, Arthur. Schawlow remained at Stanford until his appointment to emeritus status in 1991 following the death of his beloved Aurelia in an automobile accident. Over the course of his tenure there, he helped launch many graduate and postdoctoral students into eminent careers within physics, as well as pioneering new methods and applications for lasers and laser spectroscopy. He also served as a director of several companies related to the production and uses of lasers and laser spectroscopy, although he frequently joked that had he been paid for every failure in this arena, he would have been a very rich man indeed.

LASER SPECTROSCOPY

Laser spectroscopy resulted, in the memorable title of Arthur L. Schawlow's Nobel Prize acceptance speech, in putting "Spectroscopy in a New Light." In an interesting side-twist, scientific spectroscopy originated in Sweden in 1853, when Anders Ångström sent an electric spark through a gas. He produced a spectrum that included absorption lines coming from the metal electrodes but also absorption lines that were due to the presence of the gas. These absorption lines (when placed on the spectrum where the substance itself had absorbed some of the initial energy) could be used to identify unknown substances or trace elements of those substances. For example, constituent components of a gas could be determined, and light emissions from the Sun and other stars provided an indication of the gases that compose them.

With the advent of laser spectroscopy, Schawlow's work and that of his students and colleagues drastically refined levels of available precision, making possible molecular analysis. Their work enabled scientists to map out absorption lines of various gases, solids, and liquids with unprecedented detail, extending eventually down to the atomic level. As a result, the distribution of molecules and atoms within substances could be mapped. The spectra produced by this method can be used for chemical analyses, examining atomic and molecular energy levels, and determining molecular structures.

These advances enabled chemists, chemical engineers, and other scientists to obtain detailed evidence of reactions and changes within substances on scales that were previously impossible. The information obtained led to a rapid expansion of theory and a wide range of useful applications, as scientists and technologists created new materials by combining substances and both predicting and determining results from those combinations in a reasonable and accurate manner. Today, laser spectroscopy ranges from the submillimeter wavelengths of the infrared to the soft X-ray wavelengths at the other end of the spectrum. Interactions at the atomic level are now readily discernible that, prior to the advent of these approaches, were hidden from view. These developments have led to significant breakthroughs in understanding the physical world and to the design and implementation of various innovations based on these new insights.

The significance of Schawlow's work was recognized in 1981 by the award of the Nobel Prize in Physics, which he shared with Nicolaas Bloembergen, for their contribution to the development of laser spectroscopy, and with Kai M. Siegbahn, who helped develop high-resolution electron spectroscopy. Schawlow's numerous other awards include the National Medal of Science (1991), the Frederick Ives Medal from the Optical Society of America (1976), and the Liebmann Prize from the Institute of Electrical and Electronics Engineers (1964). The Laser Institute of America named its highest award for him, giving him the first Arthur Schawlow medal in 1982. He served as president of both the American Physical Society and the Optical Society of America, one of only two people to hold both positions. Diagnosed with leukemia from which he died on April 28, 1999, Schawlow spent his last few months accepting the visits of family and friends from his wheelchair and ensured that happy music from one of his beloved jazz bands was played at his funeral.

IMPACT

The range of contributions Schawlow made to physics was legion. Most important, perhaps, was his decades-long work on creating adjustable-frequency lasers. These can be tuned to desired lengths in order to be applied effectively to a range of applications, including noninvasive surgery, precise cutting of metals and other materials, measurement, and characterization of materials. Beginning in the early 1960's, Schawlow was also a major contributor to laser spectroscopy, using this tool precisely to measure and categorize spectra of molecules and individual atoms.

Schawlow also performed breakthrough work developing techniques to cancel the effects of the random thermal motions of atoms and molecules. These techniques allowed for very precise results to be obtained and became the basis for modern metrology (the science of measurement) and atomic chemistry. It was this work in particular that the Nobel Committee cited in awarding Schawlow the physics prize. In addition to his personal achievements, Schawlow instructed students who also contributed substantially to physics. One of his more famous students, Theodor Hänsch of the University of Munich, worked with him in high-precision spectroscopy and created the first continuous-beam atom laser.

Schawlow's speculations and intuition proved correct on numerous occasions. An early insight that laser light could be used to cool atoms and slow atomic motions led to several subsequent Nobel Prizes being awarded for this type of work. He was one of the first people to appreciate the importance of the different absorption properties of materials that would allow laser light to harmlessly pass through some substances while heating and destroying others. These properties led him to realize that lasers could be used for delicate, noninvasive surgical purposes, such as eye surgery.

—*Dennis W. Cheek*

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See also: Gordon Gould; Ali Javan; Theodore Harold Maiman; Charles Hard Townes.

JACOB SCHICK

American businessman

Schick spent most of his inventive efforts on developing the first successful electric razor, which could perform its operation dry, without the use of hot water, creams, or lotions.

Born: September 16, 1877; Ottumwa, Iowa
Died: July 3, 1937; Montreal, Quebec, Canada
Primary fields: Household products; manufacturing
Primary inventions: Electric razor; magazine repeating razor

EARLY LIFE

Jacob Schick was born in Ottumwa, Iowa, in 1877 and grew up in the southwestern United States. His father was a coal mine operator. By the time Jacob was sixteen, he was entrusted with the operation of a rail line that ran from Los Corrillos, New Mexico, to a coal mine his father had opened. The responsibility for this mechanical system no doubt helped him with his inventive efforts later in life. In 1898, Schick enlisted in the Fourteenth U.S. Infantry, where his close observations of repeating rifles would later be applied to one of his first commercially successful inventions.

LIFE'S WORK

After enlisting in the Army, Schick was shipped to the Philippines with the First Division, Eighth Army Corps, a few months later. He was commissioned second lieutenant and, after stateside service, returned to the Philippines, where he served from 1903 to 1905. Suffering from an attack of dysentery, he returned to the United States, where he was promoted to first lieutenant. He spent the next year recovering from his intestinal ailment.

Schick's doctor suggested that a colder climate would be good for his health, and he went to Fort Collins in Alaska to join the Twenty-second Infantry. While helping to construct one thousand miles of telegraph lines in the Alaskan interior, Schick invented the General Jacobs Boat, which was said to be well suited for use in shallow water.

Schick retired from this first stint in the Army in 1910 and went prospecting in Alaska and British Columbia. It was during this time that he became inspired to design improved shaving devices. Not realizing any commercial success from his ideas, Schick was drawn back into

Jacob Schick. (AP/Wide World Photos)

service during World War I. He returned to active duty as a captain and was placed in charge of the U.S. embassy in London. By the end of the war, he was promoted to lieutenant colonel, a title he often used for the remainder of this life.

By 1921, Schick was ready for his first business venture. He patented a shaver of standard design, except that it incorporated a feature whereby the blades could be replaced without touching them. Inspired by the Army's repeating rifles, Schick's Magazine Repeating Razor had replacement blades, stored in a clip in the handle, that could be fed in by pivoting the head and pushing a built-in lever. The razors were produced in three models between 1926 and 1935 and were the forerunners to the modern Schick Injector Razor. A drawback of these razors was that their blades required occasional replacement and had to be used with water and lotion. In 1928, Schick sold his interests in the Magazine Repeating Razor and focused on pursuing his real passion—creating an electric razor that could be used dry. Schick introduced his first model in 1931, and as the concept of dry shaving increased in popularity, a multimillion-dollar industry was born.

The Electric Razor

Today, the electric razor enjoys a multimillion-dollar market, and the name Schick is a universally recognized name identified with the razor. The story of how the idea came to Jacob Schick has several variations, but they all agree on the general location: in Alaska and British Columbia while Schick was exploring for gold in 1910.

In one variation of the story, Schick was suffering from dysentery and, finding the trip to the sink for his daily shave a difficult task, was motivated to find a simpler method. Another variation tells of Schick exploring for gold in the cold climate with a sprained ankle and with only a moose to eat during temperatures of −40° Fahrenheit. This setting motivated him to find a way to shave without the use of hot water and shaving cream. The idea that occurred to him was a shaving head driven by an external motor, but his idea was not immediately accepted by manufacturers. During World War I, he returned to active duty as a captain, putting on hold further developments of his electric device.

Schick left the Army in 1919 and concentrated on developing his Magazine Repeating Razor, which used replacement blades that were stored in a clip in the handle. In 1926, he began selling the razor, which was successful enough that he was able to sell the company to American Chain and Cable in 1928 to develop his electric shaver. In 1931, Schick introduced the handheld electric razor, considered by many to be the beginning of the modern shaving industry. The razor sold for $25, and more than three thousand were made that year. Through refinements and advertising, by 1937 there were more than 1.5 million units in use, and Schick commanded a $20 million market. The electric razor had evolved from a device that had a separate head and electric motor that required the use of two hands to a single unit that could be operated easily by one hand.

Success brings competition, and competition brings disagreements and patent arguments. Schick had his share of both: From price wars to distribution rights, his business was always plagued with turmoil. One example was Schick's involvement in 1933 with promoter Archie Moulton Andrews, chairman of Dictograph Products. Andrews received permission from Schick to sell Schick's dry shaver at the Chicago World's Fair. The trouble started after the fair, when Andrews continued to sell the shaver without Schick's consent. Shortly after, Andrews started to manufacture a rival electric shaver called the Packard Lektro-Shaver, which Schick saw as a direct patent infringement. Schick sued but lost. He continued to patent many improvements to his electric shavers and was able to become a millionaire despite fierce competition from several other manufacturers.

Schick's career, with a few minor exceptions, centered on shaving devices. One invention not related to shaving was an improved pencil sharpener (he called it a "pencil knife"), which was patented on April 29, 1924. The sharpener was shaped like a tube into which one could insert the pencil. On November 24, 1931, Schick obtained a patent for an improved engine for cars or airplanes, but the device was never commercially produced.

Schick had some unusual ideas regarding shaving and age, believing that a man could extend his life by 120 years by proper everyday shaving. His theory was that a long life involved losing the ordinary mortal awareness of time. Unfortunately for Schick, his theory did not hold true for him: He died in 1937 at the age of fifty-nine from complications after a kidney operation. He was buried in Canada at Mount Royal Cemetery in Montreal, Quebec.

Impact

Every day, millions of men and women use electric shavers. The electric shaver has secured a permanent place in technological history. The name Schick will be long remembered, in part because of brand-name recognition. Like Coca-Cola and Budweiser, Schick became a dominant player in its market.

Schick was very determined to make his electrically powered razor a success. At one point, he had to mortgage his home for $10,000 to continue his efforts. He also was one of the early pioneers in the world market. He took the ideas of capitalism to heart, and he chose to incorporate his patent-holding company, Schick Industries, in Nassau, Bahamas, so as to minimize income taxes and corporate taxes. When the Joint Congressional Committee on Tax Evasion and Avoidance looked into his arrangements, he moved to Montreal and became a Canadian citizen in 1935. For this reason, he is sometimes listed as a Canadian inventor.

—*Tom A. Hull*

Further Reading

Fucini, Joseph, and Suzy Fucini. *Entrepreneurs: The Men and Women Behind Famous Brand Names and How They Made It*. Boston: G. K. Hall, 1985. Schick is represented in very few biographical anthologies of inventors. This entry provides details of his life as they relate to his inventions.

Stuller, Jay. "It's a New Battle Every Day in the War on Whiskers." *Smithsonian* 25, no. 11 (February, 1995): 44-47. With fifteen color photographs, this eight-page article is a concise and informative overview of the history of shaving. Discusses the Schick Shaving Center, where razors are tested daily.

Time. "Dry-Shave War." November 16, 1936. Discusses the patent infringement battle between Schick and Andrews.

See also: King Camp Gillette; Paul Winchell.

BERNHARD VOLDEMAR SCHMIDT

Estonian German optical instrument designer

Schmidt invented a revolutionary telescope design that allowed a large field of view without the off-axis image distortion that characterized traditional reflecting telescopes.

Born: March 30, 1879; Island of Naissaar, Estonia
Died: December 1, 1935; Hamburg, Germany
Primary fields: Astronomy; optics
Primary invention: Schmidt telescope

Early Life

Bernhard Voldemar Schmidt (BEWRN-hahrd VOHL-deh-mahr SHMIHT) was born on an island called Naissaar (also spelled Nais Saar), located in the Gulf of Finland twelve miles north of the port of Tallinn, Estonia. His parents were Karl Konstantin Schmidt and Maria Helene Christine, née Rosen. Although they had German names and spoke German at home, they were ethnically Estonian, being embedded in a Swedish-Estonian culture. The country's complex history involved conquest by virtually all of its neighbors at one time or another, including Russia, Sweden, Poland, and Germany. The island of Naissaar was inhabited mainly by Swedish-speaking Estonians, and the Schmidts were bilingual.

Bernhard Schmidt was the oldest of six children. His father was a writer who also supported his family as a farmer and fisherman. Bernhard and his brother August were close as children, and their adventures were the subject of many (possibly apocryphal) stories. One example is the story about their attempt to create their own meteor shower by using slingshots to fling hot embers into the sky. The experiment is said to have ended when one of the "meteors" set fire to the roof of their house.

Another adventure, one that is certainly not apocryphal, involved experiments with gunpowder. Bernhard's right hand was severely damaged and, in spite of attempts to save it, doctors in Tallinn amputated the hand as well as the forearm. This loss seems to have affected his personality, but amazingly it did not affect his agility: Later in his life, he became one of Europe's most skilled opticians and lens makers.

Early evidence that Schmidt was unusually enterprising is the story that even in the year following his accident he built himself a camera with which he photographed local scenes and neighbors. He learned how to process the photographic plates and printed and sold them to locals on the island. At the same time, he became interested in astronomy, an interest that would be with him for the rest of his life.

When he was sixteen years old, Schmidt moved to Tallinn, where he was employed in a photographic studio and where his skill in retouching photos was very useful. Later, he found employment at an electric motor company. However, by 1901 he decided to improve his education. Following a brief stay at Sweden's Chalmers University of Technology, he went to Germany, where he studied at the Hochschule Mittweida.

LIFE'S WORK

Schmidt's years at Mittweida were devoted to studies of physics, especially practical and theoretical optics. At the same time, he helped support himself by making high-precision lenses and mirrors for astronomical telescopes, which he sold to local astronomy enthusiasts. By the time he had completed his studies, his reputation as a maker of fine telescope optics had spread throughout Germany, and he established a thriving business serving both professional and amateur astronomers.

Schmidt's first place of business was a small house in Mittweida, but as business grew he moved to larger quarters and hired several assistants. His shop not only made high-quality new optics but also reworked existing optics for telescopes manufactured by others. An example is the famous case in 1913 when the lens of Potsdam Observatory's twenty-inch refractor was refigured by Schmidt, resulting in much-improved performance, as demonstrated when the well-known astronomer Ejnar Hertzsprung used it to resolve and measure extremely difficult close double stars.

The optical company was soon recognized as the source of some of the world's most precise astronomical lenses and mirrors. Its reputation spread beyond Germany. For example, the University of Prague obtained two telescope mirrors from Schmidt, one that was twenty-four inches in diameter and another that was twelve inches. Business prospered, but the cloud on the horizon was the world war. Because Schmidt was from Estonia, which at that time belonged to Russia, he was arrested and confined in a prisoner-of-war camp. When the government eventually released him, he found that some of his equipment had been confiscated, making it very difficult to restart his business. Furthermore, the economy was in ruins. Germany's defeat and its following financial debacle spelled disaster for many businesses, especially for telescope makers, as German astronomers were unable to buy any equipment.

After years of declining activity, Schmidt's optical company finally had to be closed in 1926. He found refuge at the Hamburg Observatory, whose director, Richard Schorr, had corresponded with Schmidt, having recognized his genius as an optician. A laboratory and apartment were provided for him in the basement of the observatory, located near the country town of Bergedorf, southeast of Hamburg. Schmidt's duties were to maintain and improve the various telescopes of the

THE SCHMIDT TELESCOPE

Bernhard Voldemar Schmidt's most important invention is his only surviving invention, namely, the Schmidt telescope design. Although it took more than a decade for astronomers to fully appreciate its importance, the telescope eventually became a powerful new tool for astronomical research. The new design could be realized only by a revolutionary new process, which was the result of Schmidt's genius in both engineering and optics.

The most productive Schmidt telescope is the one at the Palomar Observatory in California. It has a seventy-two-inch principal mirror and a forty-eight-inch correcting lens. Built as a companion to the Palomar two-hundred-inch telescope, for many years the world's largest, the forty-eight-inch Schmidt was a workhorse that mapped large areas of sky, while the two-hundred-inch photographed small, interesting fields to fainter limits and higher resolution. In addition to various specific investigations, such as for the study of Milky Way structure and star clusters, the Palomar Schmidt carried out a massive survey of the entire sky accessible from Palomar, the Palomar-National Geographic Sky Survey. This immense atlas, completed in the 1950's, continues to be used for support of research. A second survey using the forty-eight-inch Schmidt with reworked optics was begun in the 1980's.

Other Schmidt telescopes are found at many observatories. The two-meter Schmidt at the Karl Schwarzschild Observatory in Germany is the world's largest. Others, in addition to Palomar's, are the large Schmidts at the Kitt Peak (United States), Cerro Tololo (Chile), La Silla (Chile), Tonantzintla (Mexico), Siding Springs (Australia), and Boyden (South Africa) observatories. Most Schmidt telescopes now use electronic detectors rather than photographic film or plates. Thousands of smaller Schmidt telescopes, used with a Cassegrain (two-mirror) optical design, have been produced for sale to amateur astronomers.

Although Schmidt's invention was intended as a boon to astronomy, the design has been found to be important in many other optical applications. Schmidt cameras have the advantage of great speed and clarity, and small examples have found widespread use in special-purpose photography.

observatory. The relatively free access he had to the observatory's equipment and the supportive attitude of Schorr are probably the reasons for Schmidt's crowning achievement, the invention of the Schmidt telescope.

Before 1930, astronomers were limited in their ability to photograph large areas of sky with large telescopes. Refractors (telescopes using large lenses to gather the light) could not be made very large, and reflectors (telescopes using large curved mirrors to gather the light) produced sharp images only at the center of the image. Very large mirrors could be ground and polished, but the resulting telescopes suffered from coma, the distortion of the star images off from the optical axis. Thus, only very small sections of the sky could be imaged at a time.

From the 1920's, Schmidt had determined that some solution to the problem of coma ought to be possible. He tried at least one possibility that failed before he hit on the idea of formulating a specially shaped correcting lens to be placed at the top of a telescope that would correct for the spherical aberration of a spherical mirror without introducing coma. This was a revolutionary idea, but it was difficult to make such a lens. His knowledge of optical design showed him that he needed a lens that was convex in the center and concave in the outer parts. Schmidt solved that problem in an ingenious way—using a vacuum method to pull a section of the glass into a shape that enabled him to grind it so that, when the vacuum was turned off, the glass would bounce into the shape desired. In 1930, he succeeded in making the first Schmidt telescope. It had a mirror of seventeen inches and a correcting lens fourteen inches in diameter, and it worked just as he had desired. With a fast focal ratio (f/1.75, compared to large reflectors' values of f/5 or larger), the Schmidt telescope achieved sharp images over a wide swath of the sky.

Unfortunately, the new design was too unusual for astronomers to recognize its advantages at first. Also, the worldwide depression at that time resulted in there being little opportunity for anyone to buy new telescopes. Schmidt was unable to sell his new design. He died of pneumonia in 1935 without knowing that his revolutionary telescope would one day be a supremely successful new tool for astronomical surveys of the heavens.

IMPACT

Schmidt was a skilled and inventive optician whose knowledge of both practical and theoretical optics placed him to be the creator of a revolutionary new astronomical instrument. The Schmidt telescope design had a multifaceted impact on optics. It produced a new tool that made it possible for astronomers to obtain sharp images of stars for wide areas of sky at a time, opening up powerful means for surveying the cosmos. Also, his telescope introduced a new concept: combining the power of concave mirrors with the addition of specially designed, unusually shaped lenses to achieve superior resolution for optical systems, not only for astronomy but also for many other applications in which clear, sharp imaging is the desired product.

The impact of Schmidt's invention did not occur until a few years after his death. He had discussed the Schmidt telescope design with the Germen astronomer Walter Baade in 1929, when both were on an expedition to the Philippines to observe a solar eclipse. Baade was intrigued by the possibilities that the new design would open up. A few years later, when Baade moved to the Mount Wilson Observatory in California, he had the opportunity to instigate the building of an eighteen-inch Schmidt telescope, which was a brilliant success and which led to the building of many larger Schmidt telescopes around the world.

—*Paul W. Hodge*

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See also: George R. Carruthers; Hans Lippershey; Sir Isaac Newton; Jesse Ramsden.

Ignaz Schwinn

German American mechanical engineer

Through his own innate ability, hard work, and hardheadedness, Schwinn advanced from a poor German immigrant to the head of a bicycle manufacturing company that became an exemplar for bicycle makers in the United States for nearly a century.

Born: April 1, 1860; Hardheim, Baden (now in Germany)
Died: 1948; Chicago, Illinois
Primary fields: Automotive technology; manufacturing; mechanical engineering
Primary invention: Streamline Aerocycle (Schwinn bicycle)

Early Life

Ignaz Schwinn (IHG-nahts SHVIHN), born April 1, 1860, in Hardheim, Baden (now in Germany), was the son of a piano and organ factory owner, who died when young Schwinn was eleven years old. Being next to the oldest in a family of seven children, Schwinn was required to leave school and help support the large family. He began an apprenticeship to a machinist, showing remarkable talent in this endeavor, and later began looking for work repairing high-wheeled bicycles and bicycle parts.

Life's Work

While working in bicycle factories, Schwinn learned about the new "safety," a rear-wheel, chain-driven bicycle with two wheels of similar size that was invented in 1885 by John Starley in England. Seeing possibilities in the new design, Schwinn set out to interest bicycle makers in it, but they preferred to continue producing the older high-wheel bicycles. Schwinn also saw advantages in the new pneumatic tire, which had a softer rubber than the hard tire, but most factories rejected it as an unrealistic novelty.

In Frankfurt, Schwinn worked in a machine shop that supplied parts to Heinrich Kleyer, a high-wheel bicycle manufacturer, who met and hired Schwinn. Kleyer was pleased with Schwinn's designs for the improved safety bicycle that Schwinn had worked on privately, and he gave Schwinn the opportunity to develop the bicycle. Schwinn soon became designer and works manager for the company, which produced some of the first safety bicycles in Germany. Schwinn supervised the building and equipping of a new factory for Kleyer's prospering business, which later became Adler Works of Germany.

In 1889, Schwinn arrived in the United States, settling in Chicago, where he hoped to observe the latest technical advances at the World's Fair in 1893. He worked briefly for a company that made Fowler bicycles; later, he designed the bicycles and established the bicycle factory of the International Manufacturing Company. Dissatisfied with the management, he left there in 1894 and formed a partnership with Adolph Arnold—Arnold, Schwinn & Company—in 1895. Arnold, the president of a meat-packing business and the Haymarket Produce Bank, provided the capital but allowed Schwinn to design the products and the tools, purchase machinery and equipment, hire personnel, and essentially set up the factory.

Schwinn's new bicycle factory took its place alongside thirty other bicycle factories on Lake Street and began to turn out superior merchandise. In 1896, bicycle racing was a sport sensation, and riding the Schwinn-built World Racers that weighed nineteen pounds complete, the Arnold, Schwinn & Company's team set numerous records. The world racing team won races in Italy, France, and England and set new records for the half mile and the kilometer. By the year's end, Schwinn's factory had more winners than any other bicycle factory. Racing clubs for prosperous Americans were quite popular, and tracks were built quickly. In 1902, the racing bicycle sold for $150, about $27,450 in 2000 dollars.

In the early years of the century, largely because of overexpansion and overproduction, the bicycle boom collapsed. Bicycle sales dropped to a fraction of those sold even five years earlier. Only twelve bicycle factories remained on Lake Street, as competition for parts and sales outlets was fierce. In the process of building a new factory in western Chicago, Arnold and Schwinn bought out failing factories and continued business. In 1902, Schwinn designed and built four experimental motorcars; the last one, in 1905, featured a four-cylinder, water-cooled, four-cycle engine—all furthered by the great strides of the company's forerunner, the bicycle.

In 1908, Schwinn bought out Arnold's share of the company, and although the company retained its name, Schwinn became its sole owner from that point. Schwinn's first child, Frank, was born that same year. In 1911, Schwinn bought the Chicago-owned Excelsior Motorcycle Company that, under his direction, soon became ranked with Indian and Harley-Davidson as the top three

American motorcycle manufacturers. Schwinn's company sponsored famous racing stars until World War I, sending Schwinn sales skyward. Schwinn purchased the Henderson Motorcycle Company in 1917, continuing to make motorcycles until the Great Depression, when he was forced, in 1931, to discontinue his motorcycle line.

When the advent of the automobile decimated bicycle sales, Schwinn turned his attention to the manufacture of bicycles for children. The lighter, more expensive bicycles of the 1890's were neglected in favor of the sturdier bicycles required for children and for delivery services. Mud flaps were added to the bicycles to attract youngsters, but the bicycle industry was devastated. In the early 1930's, Schwinn created a new department in his factory, one filled with workers from his defunct motorcycle line, whose duties were to search for possible improvements in the bicycle that would not include a large increase in price. In this attempt to break away from standardization, Schwinn not only weathered the Depression but also established himself as an innovative leader in the American bicycle industry.

In 1933, Schwinn introduced the first balloon-tire bicycle—with a double tube more than two inches wide—which was considered practical and durable. Although balloon tires had been used on automobiles for years, the bicycle industry was slow to accept the new design. Schwinn persisted in its adaptation, and within a few years balloon tires were standard features on all bicycles. Continuing the emphasis on innovations affecting quality, comfort, and appearance, Schwinn developed the Streamline Aerocycle in 1934. The following year, he introduced the Cycleplane, streamlined in appearance. In 1936, the Autocycle appeared, a fully streamlined bicycle featuring a full-floating saddle that brought new comfort to riders, better reflectors for night riding, double headlights, and an improved frame. In the remaining years of the 1930's, Schwinn introduced a bicycle with forewheel brakes, the spring fork for more riding comfort, and the bicycle truck made expressly for deliveries.

The beginning of World War II brought an abrupt end to the production of Schwinn bicycles as Ignaz Schwinn shifted to the production of war materials, for which his company received the Army and Navy "E" award for excellence. In 1947, Schwinn sales soared with the postwar economy's growth, reaching more than 400,000 bicycles that year. The following year, at the age of eighty-eight, Schwinn died of a stroke, leaving the Schwinn Company in the capable hands of his son, Frank, who continued to enhance the Schwinn image. As an engineer and marketing genius, Frank persisted with streamlined innovations. The Black Phantom (1949); the Panther (1950); the Starlet (1951) for girls; the Paramount (1952), said to be the best-built bicycle in America; the Wasp (1954); and the Corvette (1954) were stylish classics of the 1950's.

Frank W. Schwinn died in 1963. The company man-

The Streamline Aerocycle

Toward the end of the Great Depression, when Ignaz Schwinn and other bicycle manufacturers were struggling to survive, Schwinn employees worked doggedly to ensure Schwinn quality, to introduce new accessories, and to modernize existing bicycles. Schwinn and his son, however, were determined to take a bold step. They introduced the Streamline Aerocycle in 1934, the first departure from the standardized bicycle appearance in forty years. Influenced by the streamlined look of the airplane, the standard of design during the 1930's, Schwinn promoted the bicycle as having the "grace and beauty of the newest airliner." It featured the balloon tires that Schwinn had challenged the tire industry to produce and that had previously drawn the scorn of other bicycle makers, despite the tires' extensive use in Germany.

Balloon tires were associated with motorcycles and automobiles and were widely publicized—a fact that provided Schwinn with an image of improved durability. Moreover, the Aerocycle's teardrop-shaped tank over the crossbar, along with handlebars, grips, and accessories including headlight, taillight, and horn, all suggested the radical look of a sleek, streamlined motorcycle.

Although the Aerocycle was priced beyond the reach of most bicyclists at that time, it produced the desired effects. Imaginations were inspired, other companies began designing bicycles with new looks, and Schwinn's business improved, propelling the company into leadership during the Depression recovery. A huge sales stimulator, the Aerocycle marked a significant change in the history of the bicycle, as the bicycle market showed new signs of life and the demand for Schwinn bicycles increased. Despite its high price, the Aerocycle, one of the early "cruiser" bicycles, remained one of the most sought-after bicycles. It was replaced by Schwinn the following year with a more affordable model, the Cycleplane, which featured many of the Aerocycle's accessories and became one of Schwinn's best-selling bicycles. The Aerocycle eventually became a collector's item, a prized reminder of the innovation that kept Schwinn at the top of the bicycle industry.

agement devolved over time to his son and other family members, each less competent than the last. After a long decline, and amid family rancor and squabbling, the Schwinn Bicycle Company went into bankruptcy in 1992.

IMPACT

With the opening of his factory in 1895, Schwinn began to realize his dream, which was to build excellent bicycles. Possessing abundant knowledge about bicycles, having worked on them for many years in Germany, Schwinn began a conservatively managed company with the best machinery, equipment, and precision tools money could buy—one that could build bicycles that would last. "Schwinn-built" signs appeared in salesrooms to distinguish the bicycles with the latest innovations and accessories, and with the sturdiest frames, deemed the safest and the most durable. Schwinn went so far as to issue a lifetime guarantee with each bicycle, an astounding gesture that demonstrated Schwinn's confidence in his products. Soon, at the request of salesmen, the "lifetime guarantee" was placed on the handlebars, as the bicycling public had begun to equate Schwinn with quality.

While Schwinn's stratagems served his purpose well, his advertising methods may have reaped even greater benefits. Schwinn seemed to know what children wanted and targeted them with his advertisements. Because American youth understood from advertisements, their own observations, and by word of mouth that Schwinn bicycles were the "best," they beseeched their parents not for generic bicycles but for Schwinns. Schwinn also engaged famous actors and actresses to endorse his bicycles and to have their pictures taken while riding his bicycles. The association of the name Schwinn with quality continued for decades.

—*Mary Hurd*

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; John Boyd Dunlop; Henry Ford; Charles Goodyear; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; André and Édouard Michelin; Ransom Eli Olds; Nikolaus August Otto; Stanford Ovshinsky; Sylvester Roper; Felix Wankel; Alexander Winton.

GLENN THEODORE SEABORG

American nuclear chemist

Seaborg, the 1951 Nobel laureate in chemistry, was a leading participant in the Manhattan Project that created the nuclear bomb. A dedicated public servant, he was adviser to ten presidents, the first scientist to chair the Atomic Energy Commission, and a leading pioneer in the creation of new radioisotopes.

Born: April 19, 1912; Ishpeming, Michigan
Died: February 25, 1999; Lafayette, California

Primary fields: Chemistry; military technology and weaponry
Primary inventions: Transuranium elements; nuclear bomb; plutonium synthesis

EARLY LIFE

Glenn Theodore Seaborg (SEE-bohrg) was born in the small iron-mining town of Ishpeming, Michigan, the son of Herman Theodore Seaborg (originally Sjöberg), a first-generation Swedish immigrant, and Swedish-born Selma O. Seaborg, née Erickson. His first language was Swedish (he began his Nobel address in that language), and he was active in Swedish and Swedish American organizations.

When Glenn was ten, the family moved to a Los Angeles suburb, Home Gardens (now in South Gate), where his father unsuccessfully sought a permanent position during the Great Depression, and financial difficulties plagued the family. To earn money, Glenn mowed lawns and delivered newspapers. He and his sister Jeanette attended elementary school in Watts but finished their primary education in Home Gardens. While attending high school in Watts, Glenn took his first science course, chemistry, as a junior and decided on a career in science.

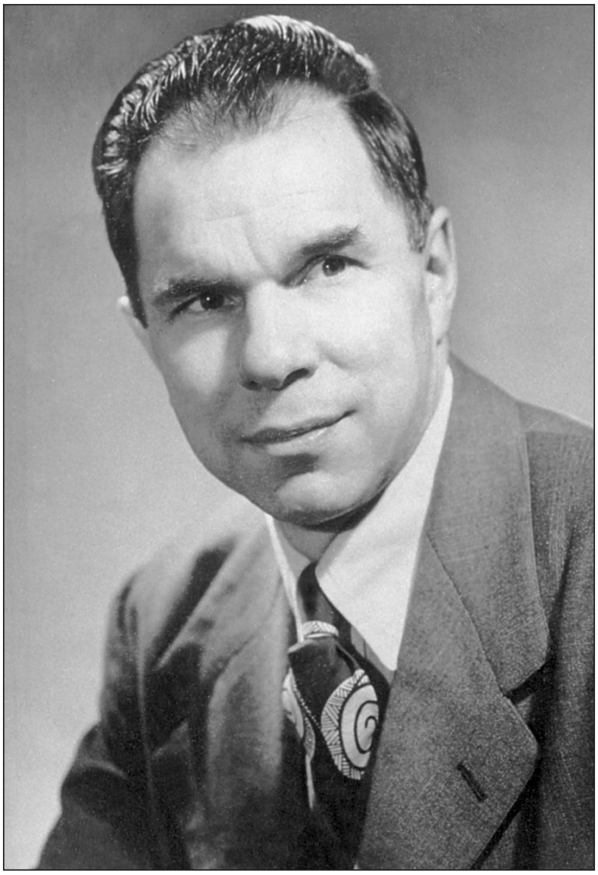
In 1929, Seaborg enrolled in the University of California, Los Angeles. He earned money by working as a graveyard-shift control chemist at the Firestone Tire and Rubber Company, as a stevedore, as an apricot picker, and as an apprentice Linotype machinist at the *Los Angeles Herald*. He preferred to major in physics but selected chemistry, thinking that it offered more job opportunities in industry.

After graduating in February, 1934, Seaborg entered the University of California, Berkeley, supporting himself with a $50 monthly teaching assistantship. In 1936, nuclear physicist Jack Livingood asked Seaborg to separate and identify radioactive isotopes from a "hot" target that had been bombarded in Ernest Orlando Lawrence's particle accelerator, the cyclotron. During the next five years, the pair isolated many isotopes used in medicine, biology, and industry. Among these was iodine 131, now used more than half a million times annually in the United States to diagnose and treat thyroid diseases. It later saved Seaborg's mother's life. Seaborg and Livingood also discovered iron 59 and characterized cobalt 60, later used in metallurgy, radiotherapy, and materials testing. In 1938, Seaborg and Emilio G. Segrè discovered technetium 99m, the most-used diagnostic radioisotope.

In May, 1937, Seaborg received his Ph.D. for research that yielded the first unequivocal evidence for the inelastic scattering of fast neutrons and established a minimum cross section for this reaction in the region of lead and bismuth in the periodic table. He remained in Berkeley as personal assistant to the College of Chemistry's dean, Gilbert Newton Lewis, with whom he coauthored several articles on acid-base chemistry.

LIFE'S WORK

Word of Otto Hahn and Fritz Strassmann's epoch-making discovery of nuclear fission by bombarding uranium with neutrons stimulated Berkeley scientists to confirm or extend their results. In May, 1940, physicists Edwin Mattison McMillan and Philip Hauge Abelson produced the first transuranium (heavier than uranium) element, atomic number 93, by a similar process. They named it neptunium for the next planet beyond Uranus. In November, 1940, McMillan was suddenly called to the Massachusetts Institute of Technology (MIT) to work on radar; Seaborg obtained his permission to continue the search, and he synthesized element 94, plutonium.



Glenn Theodore Seaborg. (©The Nobel Foundation)

Seaborg was one of the six scientists who signed the Franck Report urging that the nuclear bombs that he helped to develop be demonstrated to the Japanese rather than employed against a civilian population. The suggestion was disregarded, but Seaborg, until his death, thought that the control of nuclear weapons was the most critical problem of the time, and he was a leading figure in the campaign for nuclear disarmament.

After Seaborg finished his wartime studies of plutonium, he returned to Berkeley, where he and his coworkers, Albert Ghiorso, Ralph James, and Leon O. ("Tom") Morgan, continued their search for additional transuranium elements. Their use of chemical isolation methods, based on the assumption that the next elements (atomic numbers 95 and 96) were similar to plutonium, were unsuccessful. However, when they carried out their search according to Seaborg's actinide concept, they rapidly synthesized and identified these elements, named americium (now used in tiny amounts in every home smoke detector) and curium. Seaborg held patents on these elements, becoming the only person to hold a patent on a chemical element.

In summer, 1944, Seaborg proposed a new format for the periodic table incorporating his revolutionary actinide concept, considered the most important change in the table since Dimitry Ivanovich Mendeleyev's original design. Several inorganic chemists warned Seaborg against publishing it because doing so would destroy his reputation. He quipped, "I didn't *have* any scientific reputation, so I published it anyway."

Seaborg suggested that a new series begins with thorium (atomic number 90) and continues through all the elements beyond actinium (atomic number 89), including all the following fourteen elements, ending with element 103. He moved thorium, protactinium, and uranium (elements 90, 91, and 92) from the seventh period (horizontal row) to a new period, called actinide, parallel and similar to the so-called lanthanide (rare earth) series, cerium through lutetium (elements 58 through 71). The new actinide period was accommodated as a row of elements under the lanthanide period below the main portion of the table. Seaborg considered his new concept "the key to the subsequent discovery of a number of transuranium elements."

Seaborg announced his discovery of americium and curium on November 11, 1945, in response to a youth's question about whether any new elements had been discovered, while a guest on the *Quiz Kids* radio program. According to Seaborg, "this was the first time in the history of the world that the announcement of the discovery of chemical elements was sponsored by Alka-Seltzer."

Seaborg returned to Berkeley in 1946. Using his actinide concept and the ion-exchange technique (widely used to soften water), he and his team synthesized berkelium (element 97), californium (element 98, only a few thousand atoms isolated), einsteinium (element 99), fermium (element 100),

PLUTONIUM

Glenn Theodore Seaborg is best known for his synthesis, identification, and characterization of plutonium (atomic number 94), the second of the transuranium elements ("Plutonium Isolation," U.S. Patent number 3,000,695). He was posthumously inducted into the National Inventors Hall of Fame in 2005. He described his discovery as "the first realization of the alchemist's dream of large-scale transmutation."

On December 14, 1940, with graduate student Arthur Wahl and instructor Joseph Kennedy, Seaborg produced and identified element 94 by bombarding uranium with deuterons (heavy hydrogen nuclei) in the sixty-inch cyclotron. They submitted the announcement of their discovery, which included Edwin Mattison McMillan as coauthor, to the *Physical Review* on January 28, 1940, but for national security reasons, it remained unpublished until 1946. Their critical and unequivocal chemical identification of what they called plutonium (for Pluto, the dwarf planet after Neptune) was carried out during a stormy night on February 23, 1941, in room 307 of Gilman Hall at the University of California, Berkeley, now a National Historic Landmark designated with a metal plaque.

Like uranium 235, plutonium 239 was fissionable with thermal neutrons. Large amounts of plutonium were required for a nuclear bomb. Therefore, a crash program was initiated by the Manhattan Project at the University of Chicago's Metallurgical Laboratory. Seaborg, who was placed in charge, arrived there on his thirtieth birthday. In what he called "the most exciting and most challenging period of my life," he developed an extraction process that was used in what he described as "surely the greatest scale-up factor [ten billion] ever attempted" at the newly constructed Hanford Engineer Works in Washington State. Subsequently, when large amounts of plutonium became available, the usual chemical methods could be used, but at the time all manipulations needed to be performed in enclosed areas because of the intense radiation.

Plutonium is produced in much greater amounts than any other synthetic element. Forty percent of the energy in the nuclear reactors producing electricity in the United States is produced from plutonium 239. In fact, more energy is produced from plutonium fuel than by burning natural gas. Another isotope, plutonium 238, has numerous applications as an easily transportable source of electrical power. Transmission of information from the space probes that flew by the planets Jupiter, Uranus, and Neptune to Earth would have been impossible without plutonium.

mendelevium (element 101, only five atoms isolated), nobelium (element 102), and seaborgium (element 106). Seaborg is the only person to have an element named after him during his lifetime. In 1951, Seaborg and McMillan shared the Nobel Prize in Chemistry "for their discoveries in the chemistry of the transuranium elements."

From 1946 to 1958 and 1972 to 1975, Seaborg served as director of the nuclear chemistry division of the Radiation Laboratory (now the Lawrence Berkeley National Laboratory). He was professor of chemistry from 1971 until his death. He served as chairman of the steering committee for the Chemical Education Material (CHEM) Study, which revolutionized high school curricula in the United States and abroad, and he served on many national and state educational studies.

Seaborg died at the age of eighty-six in his home, while convalescing from a massive stroke suffered while exercising on a flight of stairs at the Boston meeting of the American Chemical Society (August, 1998). He had been the society's president in 1976.

IMPACT

Seaborg was one of the central figures in the Manhattan Project, the highly secret American program that developed the two nuclear bombs—the uranium-235 bomb (code-named "Little Boy") dropped on Hiroshima on August 6, 1945, and the plutonium bomb (code-named "Fat Man") dropped on Nagasaki on August 9, 1945. Whether the bombs needed to be used to end World War II is still a debated question.

In 1961, President John F. Kennedy appointed Seaborg the first scientist to chair the Atomic Energy Commission (AEC), a position that he occupied for ten years (1961-1971), during the Kennedy, Lyndon B. Johnson, and Richard M. Nixon administrations, where he oversaw a broad range of activities, including developing nuclear weapons and finding peaceful uses for nuclear energy. He served as an adviser to ten U.S. presidents, from Franklin D. Roosevelt to George H. W. Bush, and was an active participant in national and international policy making at the highest levels of government. He was personally opposed to deployment of antiballistic missiles (ABMs) and lobbied for the Limited Test Ban and Comprehensive Test Ban treaties. A dedicated public servant and educator as well as a pioneer in nuclear science, medicine, and energy, he was so multifaceted that the *Guinness Book of World Records* cited him for having the longest entry in *Who's Who in America*.

—*George B. Kauffman*

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Seaborg, Glenn T., with Eric Seaborg. *Adventures in the Atomic Age: From Watts to Washington*. New York: Farrar, Straus and Giroux, 2001. As the most prolific and consistent scientific diarist of the twentieth century (he began keeping a daily journal at the age of fourteen), Seaborg wrote tens of thousands of pages, from which his youngest son distilled this historically significant autobiography.

See also: Ernest Orlando Lawrence; Dimitry Ivanovich Mendeleyev; J. Robert Oppenheimer.

CLAUDE ELWOOD SHANNON

American mathematician and electrical engineer

Though a prolific inventor, Shannon is best known for two contributions. The first dealt with electronic switching, laying the groundwork for the digital computer. The second dealt with information theory, outlining the basic requirements for transmitting data.

Born: April 30, 1916; Petoskey, Michigan
Died: February 24, 2001; Medford, Massachusetts
Primary fields: Communications; electronics and electrical engineering; mathematics
Primary inventions: Electronic switching theory; information theory

EARLY LIFE

Claude Elwood Shannon was born in Petoskey, Michigan, and grew up in the nearby town of Gaylord—about 160 miles north of Detroit—far from education centers of the state. Consequently, he was not exposed to academia. His father was a judge in the city, and his mother was the principal of the local high school.

In grade school, Shannon was a typical boy: He made model airplanes and a radio-controlled boat, delivered newspapers, and once used the barbed wire around a neighbor's pasture to string a telegraph line to a friend's house half a mile away. The only activity that might pertain to his future career was his job repairing radios for a local department store. (This was in the early 1930's, when every component in a vacuum tube radio was readily identifiable.) After grade school and high school, Shannon entered the University of Michigan, and in 1936 he obtained bachelor of science degrees in electrical engineering and mathematics. That year, he accepted a research assistant position in the Department of Electrical Engineering at the Massachusetts Institute of Technology (MIT), where he worked toward his master's degree.

LIFE'S WORK

Shannon was assigned to Vannevar Bush, who at that time was building a mechanical computer, the differential analyzer. It was not an easy job; this device solved differential equations by analog means, which required translating differential equations into mechanical terms, setting up the device, and running through the needed solutions for various initial values.

Also associated with this very complex device was a relay circuit consisting of more than one hundred relays. The circuit using these relays had been designed piece by piece, and Shannon wondered if it had been done in the most efficient manner. He recalled a course he had taken as an undergraduate on what was then known as relay algebra, or Boolean algebra (named for its originator, George Boole). Shannon developed and applied these ideas during the summer of 1937, which he spent at Bell Telephone Laboratories in New York City. Back at MIT, he prepared his master's thesis, in which he showed that Boolean algebra could be used to design switching and computer circuits. He was right. Decades later, computer scientist Herman H. Goldstine called this work "one of the most important master's theses ever written . . . a landmark in that it helped to change digital circuit design from an art to a science."

In 1938, at the suggestion of Bush, Shannon changed his major from engineering to mathematics. Shannon's doctoral thesis was "An Algebra for Theoretical Genetics" (1940). Shannon's work on switching theory now led him to think in terms of time, bandwidth, noise, and distortion in communications systems, and he wrote to Bush about his ideas. Shannon spent the next fifteen years at Bell Labs, associating with many talented scientists and engineers, including Harry Nyquist, a key contributor to signal theory; Hendrik Wade Bode, known for his feedback work; William H. Brattain, John Bardeen, and William Shockley, the inventors of the transistor; John R. Pierce, who made contributions to satellite communication; and many others.

Shannon's work on switching theory and on the application of Boolean algebra to computers led him to think in terms of transmitting the developed digital data over communications channels. This field has been called information theory. Shannon noted that a communications system consists of a few basic elements: a source of information (the sender), a channel over which the information is sent (wire, fiber optics, radio), a receiver, and noise (interference will always creep in and distort or smother the information being transmitted). All is well if the information being sent is loud enough, the channel is good enough, and the noise is low enough. In the case that one or more of these conditions does not exist, the obvious solution (and one that inevitably causes problems) is to increase the power of the transmitter. A better solution, but one not always possible, is to lower the noise. Shannon concluded that, given the bandwidth of the channel and the level of noise on the circuit, it is possible to mathematically determine how much information can be transmitted over a channel. He further pointed out that the information being transmitted has the best chance of being received accurately if it is kept to a minimum—that is, prepared with a minimum of redundancy.

Shannon was known by his peers as a true genius, but he was also quite playful. Adept at using a pogo stick, he developed a motorized one. He was also adept at using the unicycle, and he developed one with an eccentric wheel, so that the rider moved up and down as he pedaled. One of his hobbies was juggling, and he decided that bounce juggling was easier than conventional toss juggling because the balls were moving at their slowest speed when captured. Shannon was an unpretentious man and was frequently seen rolling down the hallowed halls of Bell Labs on his unicycle while juggling three balls. Taking an interest in artificial intelligence, he built what he called the "ultimate machine," described by futurist Arthur C. Clarke as a wooden box with a single switch on one face. When the switch was thrown, the lid slowly opened, a hand reached out, turned the switch off, and retreated into the box. The machine did nothing except switch itself off.

More in line with Shannon's life's work was the mechanical maze-solving mouse Theseus, built in 1950. It was controlled by a circuit of some one hundred relays that moved the mouse around a maze of twenty-five squares. The maze could be altered at will, and the mouse would then search through the passageways until it found the designated destination. Most important, the mouse could remember where it had been; when re-placed in the maze (at any point), it would quickly move to the destination.

Shannon held honorary degrees from a number of universities, including Yale, Michigan, Princeton, Edinburgh, Pittsburgh, Northwestern, Oxford, East Anglia, Carnegie-Mellon, and Tufts. Throughout his career, he received numerous awards, and he was named a fellow at half a dozen universities. Shannon retired from Bell

SWITCHING THEORY

Although Claude Elwood Shannon invented dozens of products and systems—including a motorized pogo stick, a chess-playing machine, and a juggling robot—he is best known for his work on switching theory, primarily utilizing Boolean algebra, and his work on information theory, which defined mathematically the capacity of a transmission channel under varying conditions.

Shannon's work on the process of using switching theory in the design of telephone switching circuits and computer circuits took place while he was a graduate student at the Massachusetts Institute of Technology (MIT). He had been assigned to Vannevar Bush to assist in the maintenance of Bush's differential analyzer, an analog computer. Associated with this device was a circuit of some one hundred relays. Shannon wondered if this circuitry could have been designed more simply, and he thought back to his study of Boolean algebra at the University of Michigan. (George Boole's work was purely mathematical; neither telephones nor computers existed in his day.) Boolean algebra has to do with the manipulation of logic functions. In the simplest form—the binary system—something either "is" or "is not;" it is a "yes" or a "no." From a mathematical standpoint, it is a 1 or a 0. A relay (an electronic logic circuit), therefore, can be on or off, 1 or 0. Shannon called this condition of being on or off a "bit," short for "binary digit."

When huge numbers of logic functions are pieced together, it is of course advantageous to do so in the most efficient manner. By representing each of these functions mathematically and then putting them together in a mathematical equation, it is possible to simplify the equation, and therefore the equivalent circuit. This action can save huge expenses in the design of computers or telephone switching circuits.

Shannon made this effort the basis of his master's thesis, which is considered one of the most important master's theses ever written, in part because it laid the foundation for the digital age. In later years, Shannon downplayed his contribution: "It just happened that no one else was familiar with both fields [mathematics and electrical engineering] at the same time." His work earned Shannon the title of the "father of the information age."

Telephone Laboratories at the age of fifty. He succumbed to Alzheimer's disease and died in 2001.

IMPACT

Shannon is credited with two extremely important contributions to information technology. The first, developed while a graduate student at MIT, dealt with the application of Boolean theory to electronic switching, thus laying the groundwork for the digital revolution. His second contribution, a paper titled "A Mathematical Theory of Communications" and published in 1948 in the *Bell Systems Technical Journal*, described in mathematical detail the amount of information that could be transmitted over a particular channel. The maximum information transfer rate over a channel was identified as the "Shannon limit." The paper has been lauded as "The Magna Carta of the information age."

—*Robert E. Stoffels*

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See also: John Vincent Atanasoff; Charles Babbage; Clifford Berry; Seymour Cray; John Presper Eckert; Gottfried Wilhelm Leibniz; John William Mauchly; John R. Pierce; George Stibitz; Alan Mathison Turing; Konrad Zuse.

JOHN C. SHEEHAN

American chemist

Sheehan developed the first total synthesis of penicillin, opening the way for the production of the antibiotic in a pure form and for the production of specialized penicillins for a wide range of diseases.

Born: September 23, 1915; Battle Creek, Michigan
Died: March 21, 1992; Key Biscayne, Florida
Also known as: John Clark Sheehan (full name)
Primary fields: Chemistry; medicine and medical technology
Primary invention: Synthetic penicillin

EARLY LIFE

John Clark Sheehan was one of three boys born to Leo C. and Florence Sheehan. Leo was the sports editor and political writer for the *Battle Creek Enquirer*, where he later became managing editor. He died of cancer at age fifty. Florence worked as a genealogist. John was interested in chemistry at an early age and had a traditional chemistry kit, which grew into a basement laboratory. His other interests included rocketry, model airplanes, yo-yos (he was a champion), tennis, and the Boy Scouts of America. He received awards in tennis, both in singles and in doubles with his brother Joseph. He attended St. Philip High School in Battle Creek and then Battle Creek College, graduating with honors with degrees in chemistry and political science. As valedictorian of the 1937 class, he was awarded a scholarship to attend the graduate school of his choice. He received his master's and doctoral degrees from the University of Michigan in 1938 and 1941, respectively. His doctoral research was in the synthesis of phenanthrene derivatives.

In 1941, Sheehan married a high school classmate, Marion Jennings, and began postdoctoral work with his mentor, Werner E. Bachmann. Bachmann had a national defense grant to develop a synthesis for an explosive, cyclotrimethylenetrinitroamine, code-named RDX and called cyclonite. Bachmann and Sheehan developed a method to synthesize large quantities of RDX by nitration of hexamethylenetetramine. RDX was a very useful explosive, replacing trinitrotoluene (TNT) as the main explosive in rockets, bombs, and torpedoes. Sheehan also isolated another explosive, cyclotetramethylenetetranitramine (HMX), as a by-product of the RDX project.

Sheehan went to work for Merck and Company in Rahway, New Jersey, in 1941. While at Merck, Sheehan was involved in several outstanding projects, including the new synthesis of calcium pantothenate, the purification of streptomycin, and the purification of penicillin. In 1946, he became an assistant professor at the Massachusetts Institute of Technology (MIT) for half his salary at Merck. By 1950, Sheehan had proven that he was one of the most capable scientists in the field of organic synthesis. He was promoted to associate professor in 1948 and full professor in 1952.

LIFE'S WORK

Sheehan worked on many projects besides penicillin. He developed a new method to synthesize peptides—the carbodiimide method for forming amides. Further studies with the carbodiimides (molecules with a carbon double-bonded to two nitrogen atoms) led Sheehan to develop a gelatin that would not melt at room temperature. Gelatin, a form of collagen, is held together by weak hydrogen bonds and will remain semisolid at low temperature. The carbodiimide caused amide bonds to form, making the gelatin more stable at room temperature. Sheehan also proved that carbodiimides will cure leather. He developed three new methods to synthesize beta-lactam rings, and he did research in amino acids, alkaloids, steroids, and the synthesis of high explosives.

Sheehan began working on the synthesis of penicillin in 1948, receiving funding from Bristol Laboratories in Syracuse, New York. Nine years later, he and his team successfully synthesized penicillin V. Among his most important discoveries was ampicillin, a penicillin derivative that could be taken orally. Unlike ampicillin, penicillin is acid-sensitive and so cannot be taken orally. Ampicillin became an important antibiotic, as it had broad-spectrum antibacterial activity. For many years, Sheehan and MIT fought over the patent rights to penicillin synthesis. The rights were finally granted to MIT and generated millions of dollars for the institute. In 1992, the year Sheehan died, MIT named a professorship for him.

SYNTHETIC PENICILLIN

John C. Sheehan took on the challenge of synthesizing penicillin in 1948. He approached the task in a systematic way, developing methods to make one part of the molecule at a time. While working on synthesizing penicillin, he learned enough about the reactions of the different chemical groups of penicillin to be able to form new synthetic derivatives of penicillin that could be used to treat particular diseases.

The beta-lactam ring of penicillin plays a key role in the antibiotic. It is also a chemical structure that, if opened, deactivates penicillin. One of the major problems Sheehan faced in the synthesis of penicillin was putting together the elements of penicillin's two rings and then closing the beta-lactam ring. Adding the remainder of the molecule without opening the beta-lactam ring was another problem for Sheehan and his research team.

Sheehan first worked on forming amide bonds. Two amino acids can be connected by an amide bond to form a peptide. The systems of humans and animals do this to form proteins. Though there were ways to do this chemically, all of the methods available at the time harmed the remainder of a penicillin molecule. Sheehan found a new way to form the amide bond by using a carbodiimide, a molecule with a carbon doubled-bonded to two nitrogen atoms. This was a revolutionary way to form amide bonds under mild conditions. This discovery set the stage for the synthesis of penicillin. If Sheehan could put all of the elements in place, the carbodiimide reaction would close the beta-lactam ring by forming an amide bond.

The first step of the synthesis was to form the five-element ring. Next, scientists either closed the beta-lactam ring and added the amide with a side chain attached, or attached the amide with a side chain and then used a carbodiimide to close the beta-lactam ring. One important consideration was the groups attached to the first compounds used to form the five-element ring. Those groups were to protect the ring and the nitrogen and carbonyl groups so that they would be active at the time to close the beta-lactam ring. The protecting groups also had to be easy to remove after their task was accomplished. Sheehan found several protecting groups that worked. One bulky group also helped close the beta-lactam ring. New derivatives of penicillin are formed by changing the side-chain group.

Penicillin derivatives such as ampicillin were found to be more effective than original penicillins in treating a wide range of bacterial infections.

Although penicillin is not a large molecule, it is unstable, with a beta-lactam ring that can be easily opened. A beta-lactam ring has a carbonyl group: a carbon double-bonded to an oxygen atom, which is bonded to a nitrogen atom, forming an amide bond. Two additional carbons make up the remainder of the ring. In the penicillin molecule, the nitrogen and one carbon are also part of a second five-element ring consisting of the nitrogen and carbon in the beta-lactam ring, a sulfur atom, and two carbons. One carbon has a carboxylic acid group attached to it; the other has two methyl groups attached. The carbon in the beta-lactam ring that is not part of both rings has a nitrogen atom attached to it that is part of an amide group. A side-chain group is then attached to the carbonyl carbon of the amide group. Penicillin works by attaching to an OH group in an enzyme that forms cell walls for bacteria. Human cells do not have the same type of cell walls and are not attacked by penicillin. The amide bond in the beta-lactam ring breaks to allow the carbonyl group to attach to the oxygen of the OH group on the enzyme. Thus, the beta-lactam ring is the key to the action of penicillin.

Besides his work at MIT, Sheehan headed a research group at the Research Institute for Medicine and Chemistry in Cambridge, Massachusetts, where he researched water-soluble carbodiimides and the synthesis of aldosterone. He also set up the nonprofit John C. Sheehan Research Institute, funded by research grants. Though initially successful, it later suffered from poor management. During 1953-1954, Sheehan served as scientific liaison officer for the Office of Naval Research with the U.S. embassy in London. He was a scientific adviser to Presidents John F. Kennedy and Lyndon B. Johnson from 1961 to 1965.

Sheehan received many awards for his work. He was awarded honorary doctorates from the University of Notre Dame and the Stevens Institute of Technology and was a member of the National Academy of Sciences. The American Chemical Society presented him the Award in Pure Chemistry (1951) and the Award for Creative Work in Pure Chemistry (1959). In 1964, the city of Philadelphia awarded Sheehan the John Scott Award and Medal, crediting him with “saving millions of lives.” Elias James Corey, who won a Nobel Prize in Chemistry (1990) for developing the theory and methods of chemical synthesis, credited Sheehan and his colleagues at MIT with beginning the work for which Corey won the Nobel Prize.

Sheehan published more than 150 research papers and was granted some forty patents during his career. In 1977, he retired and was named professor emeritus and senior lecturer. Sheehan died of congestive heart failure at his home in Key Biscayne, Florida, on March 21, 1992. He was survived by his wife and three children.

IMPACT

During World War II, about eleven hundred scientists in thirty-nine labs in Great Britain and the United States worked unsuccessfully (at a cost of $20 million) to synthesize penicillin. Sheehan undertook the task after the war and succeeded in 1957. The synthesis led to commercial mass production of purer and improved penicillin at a lower cost than fermentation penicillin. People could afford penicillin to treat their particular ailment. By changing the side-chain groups of penicillin, scientists could alter the penicillin to treat different strains of bacteria. Different penicillins could treat diseases for which there had been no antibiotic treatment before.

Fermentation penicillin could treat only gram-positive microorganisms such as staphylococci, but not gram-negative microorganisms such as salmonellae. A derivative of penicillin, ampicillin attacks both gram-positive and gram-negative microorganisms. Also, fermentation penicillin is deactivated by acid and cannot be taken orally. Ampicillin can be taken orally. Some microorganisms are resistant to penicillin because they deactivate penicillin by opening the beta-lactam ring. By adding molecular groups to protect the beta-lactam ring, scientists have been able to develop penicillins such as staphcillin, methicillin, and oxacillin that are less likely to be deactivated. The method of modifying a drug to treat a specific problem is still used today.

—*C. Alton Hassell*

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See also: Dorothy Crowfoot Hodgkin; Max Tishler; Selman Abraham Waksman.

PATSY O'CONNELL SHERMAN

American chemist

Sherman was a Minnesota Mining and Manufacturing Company (3M) chemist best known for her role in the development of 3M's successful line of Scotchgard textile-protector products.

Born: September 15, 1930; Minneapolis, Minnesota
Died: February 11, 2008; Minneapolis, Minnesota
Also known as: Patsy O'Connell (birth name)
Primary fields: Chemistry; household products
Primary invention: Scotchgard

EARLY LIFE

Patsy O'Connell Sherman was born Patsy O'Connell in 1930 in Minneapolis, Minnesota. Her father was interested in science, and he encouraged and challenged his daughter to develop her own scientific curiosity about the world around her. She attended Minneapolis North High School. She once told a teacher that she was interested in becoming a nuclear physicist, an aspiration that won her the class title of "Most Confused Person." In 1947, she and her classmates were given an aptitude test, one for boys and one for girls. Her results suggested that she would make a good housewife. She demanded to take the boys' test instead. The retest results indicated that she should pursue a career as a chemist. She had never so much as taken a high school chemistry course. Still, she found the idea of a science career compelling, and she decided to study chemistry once she entered college.

In 1948, she graduated high school and began her undergraduate studies at Gustavus Adolphus College in St. Peter, Minnesota. She received bachelor's degrees in chemistry and mathematics in 1952. From college, she went to work as a chemist for the Minnesota Mining and Manufacturing Company, or 3M, in St. Paul, Minnesota. She was one of the first female chemists to be employed there. Her position was considered temporary; the expectation was that, being a woman, she would eventually marry and leave her scientific work behind to raise a family. The young chemist married Hubert T. Sherman the year after she began her job at 3M, but she did not abandon her new career.

LIFE'S WORK

It did not take long for Sherman to distinguish herself at 3M—thanks to a fortuitous accident and her response to it. Initially, she was assigned to work on a government contract to develop rubber hoses that could withstand exposure to jet aircraft fuel without decomposing. In 1953, she and colleague Samuel Smith were experimenting with a fluorochemical rubber. A small vial of the sticky experimental mixture fell on the floor and splashed on a laboratory associate's canvas tennis shoes. Attempts to clean the shoes failed; the rubbery substance resisted water, soap, various solvents, and scrubbing. Seeing how the fluorochemical mixture stood up to water and oily liquids made Sherman and Smith wonder whether a similar material could be created that would protect fabrics from spills and stains. With permission from 3M, the two chemists turned the focus of their research from jet fuel hoses to stain-proof textiles.

The original fluorochemical mixture was too sticky for use as a fabric treatment, so the team worked to synthesize something new. Their first attempts yielded a material so gummy that it left behind a sticky residue when the treated fabric was run through mill machinery. Subsequent formulations were too hard and brittle, so that the material became powdery when passed through mill rollers. Sherman was unable to be present during this testing phase, as women were not allowed inside the textile mills.

Eventually, Sherman and Smith hit upon an effective and commercially viable formulation. The first Scotchgard product, a stain repellent for wool, reached the mar-

SCOTCHGARD

Scotchgard protectors are fluorochemical treatments that coat a fabric or other surface to render it impenetrable to dry soil, water-based soils, and oils. The treatment may be applied by the consumer (typically from a spray can), by a professional applicator, or by the manufacturer. The product consists of a fluorochemical surfactant chemically bound to a polymer. Fluorochemicals are the most effective class of materials for repelling soils and stains found to date. The rigid carbon-fluoride structure of the surfactant keeps liquids from penetrating textile fibers and makes it difficult for dirt particles to cling to the fibers.

Today, upholstery, carpets, and other interior-design textiles are routinely pretreated by the manufacturer to make them stain-resistant, as are many items of clothing. The Scotchgard family of products has expanded to include easy-to-clean flooring, paints with built-in stain resistance, an algae-resistant roofing system, automobile care products, high-gloss waxes for boats, waterproofing for outdoor recreational equipment, and even antistatic eyewear lenses that resist smudges and scratches. All of the products in the Scotchgard line are intended to make items look newer longer, so that they need not be replaced as frequently.

Unfortunately, the popularity and ubiquity of these products during the latter half of the twentieth century has had unexpected environmental implications. Perfluorooctanyl sulfonate (PFOS), a fluorochemical used in the production of the original Scotchgard formulation, has spread throughout the environment. It is estimated that 95 percent of the people living in the United States would test positive for PFOS or related compounds. Once in the body, the chemical persists for years. Its presence in the environment is not limited to areas where PFOS is manufactured or used: It has been detected in dolphins and Arctic wildlife.

The impact on health and the environment is still being studied. According to the Minnesota Mining and Manufacturing Company (3M), research has shown no adverse human health effects even in workers exposed to higher concentrations of PFOS than the general public. Some adverse affects have been noted in animal studies involving significantly higher doses.

It is believed that, before 3M's 2000 phaseout of products having perfluorooctanyl chemistry, precursor chemicals to PFOS were released into the air during product manufacturing or application (industrial and home). Unbound residues could also escape from newly treated surfaces. Another suspected source is older treated surfaces, in which wear has broken the bonds between surfactant and polymer. Once airborne, the fluorochemicals are carried aloft, where they disperse and break down into the persistent PFOS that finds its way into wildlife and people.

Scotchgard stain protectors are not the only culprits in the worldwide spread of PFOS. Other PFOS-related fluorochemical products have included firefighting foams and food wrappers. 3M's reformulated Scotchgard products use perfluorobutane sulfonate (PFBS), a fluorochemical with a shorter carbon-fluorine chain length than PFOS. While it demonstrates some environmental persistence, PFBS has minimal toxicity and does not bioaccumulate.

ket in 1956. By that point, the two chemists had realized how well they worked together, and they continued to collaborate in expanding the Scotchgard line. Over the next several years, products for protecting upholstery, carpets, clothing, and household linens followed. In the late 1960's, Sherman and Smith created a product that not only repelled stains but also permitted the removal of oily soils from permanent-press fabrics and other synthetics. By then, Scotchgard was a trusted household name: When the product was made available to the public, quantities the manufacturer expected would last a year were sold out in a matter of days. The Scotchgard family of stain repellants and soil removers would ultimately include a hundred commercially applied and six consumer-applied products and bring in more than $300 million a year for 3M. Sherman and Smith were the corecipients of thirteen U.S. patents in fluorochemical polymers and polymerization processes. The chemist team was not issued a patent for Scotchgard until 1971.

During her four decades at 3M, Sherman served variously as a product development manager, a research specialist, and a research manager in the company's chemical resources division. In 1974, she became the first woman inducted into 3M's prestigious Carlton Society, an honorary organization for outstanding technical employees. In the mid-1980's, she created and headed 3M's technical education department, which provided continuing technical education for the company's staff.

Colleagues regarded Sherman as a great scientist who was open-minded, innovative, quick-thinking, and witty. She retired from 3M in 1992 (as did lab partner Smith, who had begun working at 3M a year before her). After retirement, Sherman channeled her love for chemistry into mentoring those interested in science careers. She often gave lectures on science, invention, and innovation.

In 2000, 3M announced that it would be phasing out production of products having perfluorooctanyl chemistry. Scotchgard, which was manufactured using perfluorooctanyl sulfonate (PFOS), was among these products. Low levels of the environmentally and biologically persistent PFOS had been detected in wildlife and people worldwide. Human health and ecological implications are still being evaluated. 3M is now manufacturing a reformulated Scotchgard using a fluorochemical that does not bioaccumulate.

Sherman was a member of the American Chemical Society for over half a century. She served on the Minnesota State Board of Inventors and the board of the National Inventors Hall of Fame. She and her husband had two daughters. One of them, Sharilyn Loushin, is a 3M chemist like her mother; the other, Wendy Heil, is a biologist who runs a precision optics company. Sherman outlived both her husband, who died in 1996, and her lab partner Smith, who died in 2005. She died in 2008 at the age of seventy-seven, a few months after suffering a stroke.

IMPACT

Sherman entered the workforce at a time when relatively few women were employed in the sciences and even fewer were trying to build a career there. Defying expectations, she succeeded as a chemist and as an inventor. She transformed an accidental spill into a serendipitous discovery, which ultimately translated into an important, popular, and long-lived product line for a major corporation.

Sherman was an excellent role model for young people—particularly girls—interested in science. She loved her work and was eager to share that enthusiasm with others. She stressed the importance of following discoveries wherever they might lead, even if they went in unexpected directions. She advocated remaining open to the accidental and the unanticipated, observing carefully, asking questions, working collaboratively, and thinking creatively.

Her importance as an inventor is reflected in the many awards and distinctions conferred upon her. She was inducted into the Minnesota Inventors Hall of Fame in 1989 and the National Inventors Hall of Fame (along with Samuel Smith) in 2001. She received the Distinguished Alumni Citation from Gustavus Adolphus College (1975) and the Joseph M. Biedenbach Distinguished Service Award from the American Society for Engineering Education (1991). She was one of the female inventors featured in the U.S. Patent Office's 1990 special exhibit, "A Woman's Place Is in the Patent Office." In 2002, she was one of thirty-seven American inventors invited to speak about the process of invention at the U.S. Patent Office's bicentennial celebration.

—*Karen N. Kähler*

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See also: Richard G. Drew; Stephanie Kwolek.

WILLIAM SHOCKLEY

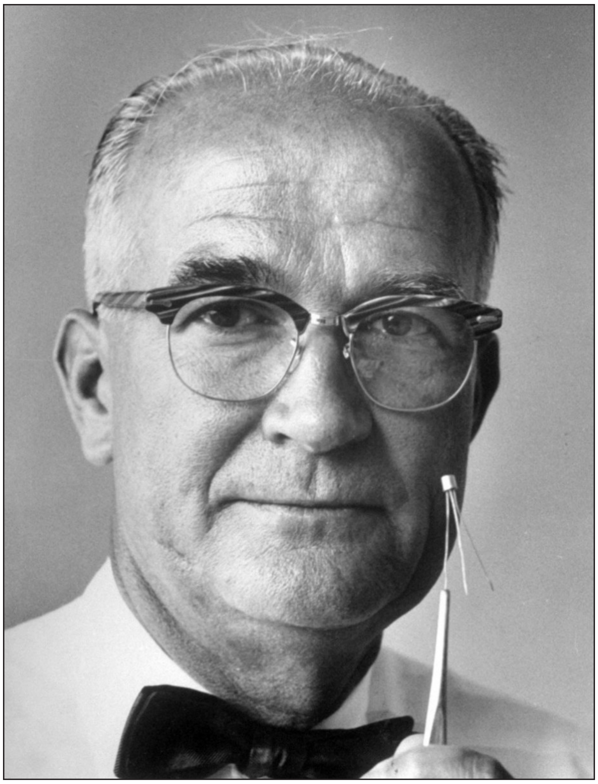
American engineer

Shockley invented the junction transistor, a device that revolutionized the electronics industry. For their invention of the transistor, Shockley, William H. Brattain, and John Bardeen were awarded the 1956 Nobel Prize in Physics.

Born: February 13, 1910; London, England
Died: August 12, 1989; Stanford, California
Also known as: William Bradford Shockley (full name)
Primary fields: Electronics and electrical engineering; physics
Primary invention: Junction transistor

EARLY LIFE

William Bradford Shockley was born on February 13, 1910, in London, England, to American citizens: William Hillman Shockley and May Bradford Shockley. In 1913, the Shockleys moved from London to Palo Alto, California, near the Stanford University campus. Coping with William's frequent tantrums, his parents taught him at home before enrolling him in a private school in 1918. In 1920, concerned that their son was insufficiently disciplined, they enrolled him in a military academy. In 1923, the Shockleys moved to Los Angeles, where William entered Hollywood High School and where, in 1925, his father died. In high school, young Shockley excelled in mathematics and science, tending to find faster ways to solve problems than those his teachers presented.



William Shockley uses tweezers to hold up one of the early models of the junction transistor. (Time & Life Pictures/Getty Images)

In 1927, Shockley attended the University of California, Los Angeles, but he enrolled the next year at the California Institute of Technology, where he majored in physics and avidly studied quantum mechanics. Having received a bachelor's degree in June, 1932, Shockley entered graduate school three months later at the Massachusetts Institute of Technology (MIT). During the summer of 1933, he married Jean Bailey, and their daughter, Alison, was born the next year. In June, 1936, with a dissertation on the movement of electrons through sodium chloride, Shockley received his doctorate in physics.

LIFE'S WORK

In that year, Bell Telephone Laboratories hired Shockley. In 1938, he joined a research team studying solid-state physics. Late in 1939, he realized that in theory there could be solid-state amplifiers that used semiconductors, which would replace vacuum tubes, which needed warm-up time and were energy-inefficient, short-lived, fragile, voluminous, and costly.

Early in 1940, Shockley used a piece of weathered copper screen to try to build a copper-oxide amplifier. Delicately, he placed a wire on either side of the screen so that the wire barely touched the copper-oxide exterior. His intent was to control the current between the two wires by controlling the voltage on the screen, but he failed. Then Shockley turned to Walter H. Brattain, a physicist with better laboratory skills than Shockley. Brattain worked under Shockley's supervision to cut grooves into sheets of copper and then oxidize the surface to bury the copper itself beneath the copper oxide. Again, the result was failure.

By then, the United States seemed headed toward World War II, which had already started in Europe, and Shockley turned to military research. Late in October, 1940, he was working at Bell Labs on improving radar, but in May, 1942, he took a leave of absence so that, as a civilian, he could conduct operations research for the U.S. Navy. In addition to explaining why American depth charges dropped from airplanes were not sinking German submarines, he used statistics to tell the Navy how it could more efficiently search for submarines and how its convoys might better avoid bombers. Shifting his civilian work entirely to the Army Air Forces (direct precursor to the U.S. Air Force) by January, 1944, Shockley worked around the world to develop training methods for airmen who would use radar bombsights.

In 1945, with the end of the war approaching, Shockley returned to Bell Labs, while maintaining his military ties. The company picked him to lead a team to research semiconductors at the laboratory in Murray Hill, New Jersey. Among his teammates were Brattain and eventually John Bardeen, another physicist. Building on a discovery at another laboratory, Shockley tried to develop a solid-state amplifier with silicon or germanium as the semiconductor and with an external electric field to control the current within the semiconductor. In a series of experiments in 1945, he expected a big increase in current in the circuits he had designed, but there was no change. Bewildered by his failure, Shockley turned to other work and left the development of a solid-state amplifier to scientists whom he supervised.

THE JUNCTION TRANSISTOR

A semiconductor is a solid that ordinarily conducts electricity slightly but not much. Originally, the semiconductor in the junction transistor was germanium, which was eventually largely replaced by silicon. As William Shockley realized, his transistor looked a little like a sandwich but worked like a faucet.

In its simplest form, the junction transistor has a positive (P) charge layer sandwiched between two negative (N) charge layers. Whether the layer is P or N depends on the substance used to make it impure—that is, to dope it. In the negatively charged layers, there are excessive electrons, while in the positive layer there are excessive "holes," which are absences of electrons in the bonds between atoms. In his book *Electrons and Holes in Semiconductors* (1950), Shockley acknowledges that holes, in this sense, are abstractions, but remarks that they are experimentally useful.

Because opposite charges attract each other, holes will flow toward electrons. More important, in the junction transistor, electrons will flow toward holes; electrons, in other words, will be the majority carrier in the NPN arrangement. If there are electrical contacts on each layer of the sandwich, a little added positive voltage on the P layer (the base) will cause, within limits, a large flow of electrons from one N layer (the emitter) to the other N layer (the collector); a small decrease in that voltage on the P layer will greatly reduce the flow of electrons. Thus, the P layer works with electrons in the junction transistor as, in a sink, the handle of a faucet works to increase or decrease the flow of pressured water through the faucet.

Transistors are the building blocks of modern solid-state electronic devices. They replaced vacuum tubes, which were bulky, energy-inefficient, and unreliable; thus, transistors led to the development of computers that were smaller, more efficient, and less expensive than the previous generation.

On December 16, 1947, Brattain and Bardeen invented a working semiconductor amplifier—specifically, a point-contact transistor, although Bell Labs had not yet coined the word "transistor." That invention marked a decline in group harmony. While happy about the invention, Shockley felt angry that he had not closely participated in what Brattain and Bardeen had done and felt driven to improve on their accomplishment. On December 12, 1947, and again two weeks later, Gerald Pearson of Bell Labs obtained the field effect that Shockley had failed to obtain in 1945. Drawing from what Pearson had achieved, as well as from what Brattain and Bardeen had invented, Shockley worked intently during a professional visit to Chicago from late December, 1947, to early January, 1948, and designed a sandwich arrangement in which a layer of positive-type (P-type) germanium would be on either side of a layer of negative-type (N-type) germanium. Thus, two PN junctions would replace Brattain and Bardeen's delicate point contacts.

Back at Murray Hill, Brattain and Bardeen had considered a patent. When Shockley returned from Chicago, he dismayed them by saying that there should be a broad patent in his name alone, because of his idea in 1945 about the field effect. The lawyers in the patent office would likely have filed for a patent in Shockley's name only, but they discovered something he had not known: In 1930, an obscure physicist named Julius Lilienfeld had received a patent for essentially the same idea. Bell Labs would therefore file for a patent on the point-contact transistor in the names of only Brattain and Bardeen.

Intensely competitive, Shockley suffered from sleeplessness because he felt defeated by two colleagues. On January 23, 1948, he had an idea of immense technological consequence. Instead of the PNP sandwich-style amplifier, which he had designed in Chicago, Shockley secretly designed a solid-state amplifier, still in sandwich style, with an NPN arrangement—one in which electrons would be the main carriers of charge. It was not until February 18 that Shockley revealed his new idea to his surprised colleagues, including Brattain and Bardeen.

The invention of the junction transistor marked the peak of Shockley's scientific career. Meanwhile, as discord within Bell Labs led to Bardeen's departure and Brattain's reassignment, there was discord in Shockley's family. Even before World War II, his marriage was troubled, and his frequent absences from home during the war and an episode of severe depression in 1943 made his family life even worse. His relationships with his sons—Billy, born in 1942, and Dick, born in 1947—were emotionally distant at best. Characteristically honest, Shockley acknowledged, despite his employer's publicity, that Brattain and Bardeen had beaten him to the invention of a solid-state amplifier. On leave again from Bell Labs, Shockley taught at the California Institute of Technology, but he wanted to run his own company to develop electronic devices.

In 1955, after Jean Shockley seemed to be recovering from cancer, he asked her for a divorce and, receiving it, married Emmy Lanning, a psychiatric nurse whom he had met the year before. Furthermore, with the support of Arnold Beckman, Shockley resigned from Bell Labs and founded the Shockley Semiconductor Laboratory as a subsidiary of Beckman Instruments; he chose the Stanford area as his workplace. He hired a group of young scientists who he thought would make the business successful. Shockley, however, showed again the abrasiveness that had offended colleagues at Bell Labs. In 1957, eight scientists left the company because of Shockley's mismanagement. He hired others, but his company never made a profit. Before his company's eventual demise, his interest had turned to teaching at Stanford.

Surprisingly, in the light of his difficult personality, Shockley was a successful teacher. Few persons could solve problems in science and engineering as well as Shockley, and he taught students his methods. However, in the opinion of many observers, Shockley tarnished his reputation, beginning in the 1960's, by his self-publicized pronouncements about what he considered the dysgenic effect in developed countries of excessive reproduction among people with low intelligence. An expert in statistics, if not in genetics, Shockley made enemies by claiming that, despite brilliant individuals within the African American population, the mean intelligence quotient (IQ) among blacks was significantly lower than that among European Americans and that this disparity was largely the result of genetic differences. Actually adding little of substance to the scientific debate about the relative contributions of heredity and environment to human intelligence, Shockley nevertheless brought to the public a topic about which many other scientists feared to talk.

As Shockley focused on eugenics and exposed himself to verbal attacks, he became distrustful of almost everyone except his second wife. After his mother died in 1977 (the same year Jean Shockley died), he was emotionally close only to Emmy Shockley. When diagnosed with metastasized prostate cancer, he refused to let anyone call his children, and he ordered his wife not to notify them upon his death, which came on August 12, 1989.

IMPACT

Despite being likened to a Nazi in his later years, Shockley helped defeat Germany and Japan in World War II and saved thousands of Allied lives through his work with the U.S. military. Furthermore, he took part, though indirectly, in the invention of the first transistor—Brattain and Bardeen's point-contact device—and won with them the 1956 Nobel Prize in Physics. Although the point-contact transistor was used awhile in such machines as hearing aids, it was Shockley's junction transistor, made first at Bell Labs by Morgan Sparks and Robert Mikulyak, that led to an age of electronics, an age of miniature radios, pocket calculators, laptop computers, cellular telephones, and numerous other devices that depend on transistors deriving from Shockley's great invention. Finally, Shockley in effect chose where Silicon Valley would be when he chose Northern California as the location of his laboratory. As a result of his inability to work with his employees, he inadvertently led several of them to form another company, Fairchild Semiconductor, which prospered and became an ancestor of most of the other companies in Silicon Valley. Often selfish, sometimes arrogant, Shockley massively changed the world.

—*Victor Lindsey*

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See also: John Bardeen; Walter H. Brattain; Lee De Forest; Calvin Fuller; Jack St. Clair Kilby; Robert Norton Noyce; Claude Elwood Shannon.

CHRISTOPHER LATHAM SHOLES

American newspaper editor and mechanical engineer

Sholes is the inventor of the first commercially viable typewriter and the developer of the QWERTY keyboard, the system that is still in use today on word processors and computers.

Born: February 14, 1819; Mooresburg, Pennsylvania
Died: February 17, 1890; Milwaukee, Wisconsin
Primary fields: Mechanical engineering; printing
Primary inventions: QWERTY keyboard; practical typewriter

EARLY LIFE

Christopher Latham Sholes was born on February 14, 1819, in Mooresburg, Pennsylvania. As a teenager, he moved to Danville, where he apprenticed to a printer. He joined his brothers Henry and Charles in Green Bay, Wisconsin, when he was eighteen. There his experience as a printer landed him the position of editor of the *Wisconsin Enquirer*, where he worked for about a year. He relocated again, this time to Kenosha, where in 1845 he became the publisher and editor of the *Southport Telegraph*. He continued to publish the newspaper for seventeen years.

Sholes decided to enter politics, and he was elected to the Wisconsin senate for two terms—first from 1848 to 1849 and then from 1856 to 1857. In the years between these terms, he served in the Wisconsin State Assembly, from 1852 to 1853. In 1860, he became the editor of the *Milwaukee News*, but he soon left the newspaper to become editor of the *Milwaukee Sentinel*. During the Civil War years, Sholes was the Milwaukee postmaster until he was appointed by President Abraham Lincoln to be the Milwaukee port collector. As port collector, he had some free time to pursue his other interests, one of which was developing mechanical typing machines.

LIFE'S WORK

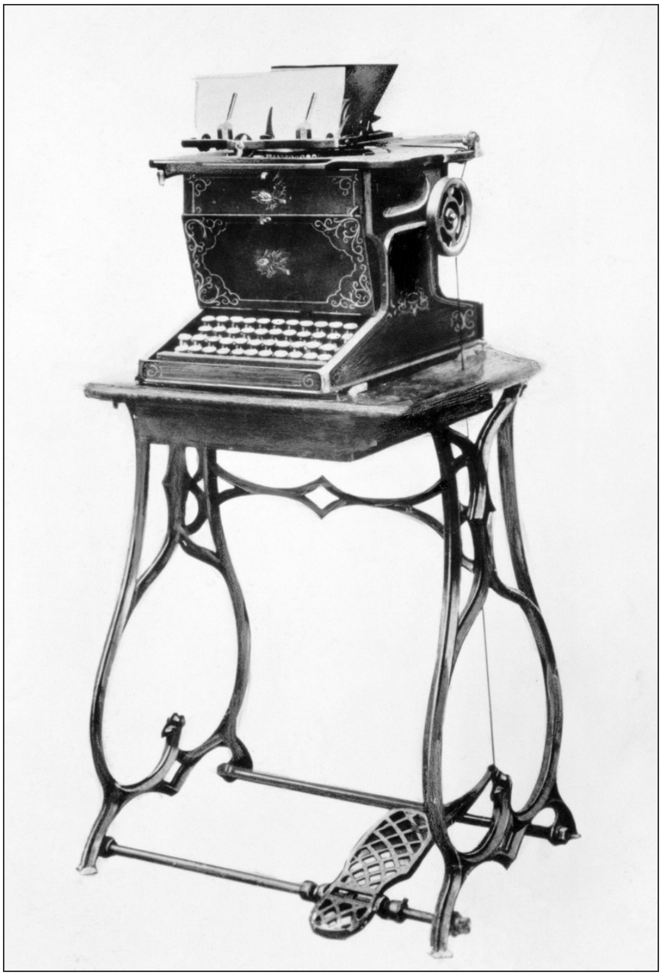
In 1864, Sholes and fellow inventor Carlos Glidden collaborated on developing a machine that could sequentially number pages in book folios. They based this new design on a machine that Sholes and another inventor, Samuel Soulé, had built to sequentially number railroad tickets. One day, Glidden read an article in *Scientific American* that described the Pterotype, a writing machine built by John Pratt in London, and showed it to Sholes. The two men resolved to attempt to rework their numbering machine to make a writing machine.

Sholes, Soulé, and Glidden began work on their writing machine in 1867 in a local machine shop owned by C. F. Kleinsteuber. Their first prototype used a bar attached to a telegraph key to move the type up when the key was pressed down. They filed for a patent for this design on October 11, 1857. Sholes parted ways with Glidden and Soulé after filing the patent. Needing financial support for his enterprise, Sholes entered into a partnership with James Densmore, who, for 25 percent of the patent rights, agreed to pay off Sholes's debts and to provide future financing. Densmore saw the commercial potential of the writing machine and hoped to profit from his partnership with Sholes.

Densmore filed a patent application on May 1, 1868, for an improved model of the writing machine that used a modified piano keyboard to move the type bars. Sholes continued working on improvements to the machine and by 1872 had constructed more than twenty-five prototypes. In 1870, Densmore made his first attempt to sell

Sholes's writing machine. He offered it exclusively to the Automatic Telegraph Company for $50,000. Thomas Alva Edison told the company that he could make a better machine for less money, so the company declined Densmore's offer. Edison was never able to make good on his offer.

Densmore then partnered with George Washington Newton Yost, an entrepreneur who sold petroleum and invented farm machinery. Together they sold the writing machine to E. Remington and Sons in March, 1873, for $12,000. Since the end of the Civil War and hence a decreased demand for their firearms, Remington had begun manufacturing farm implements and sewing machines and was interested in other inventions that it could profitably manufacture. The first typewriter that Remington produced, dubbed the Sholes and Glidden typewriter, had problems with jamming. The bars that held the type moved slowly enough that if the typist typed too quickly, they would jam up against each other. The first typists used the "hunt and peck" method of typing, so Sholes thought that if the most commonly typed pairs of letters were positioned far apart from each other, typists would take longer to move their index fingers the distance from one letter key to the next and therefore have less of a chance of typing too rapidly and jamming the bars. (Sholes at first thought that no one would ever type faster than about twenty words per minute, the equivalent of writing by hand.) Sholes's first keyboard had the keys arranged alphabetically, based on the way newspaper printers' letters were arranged. The new arrangement earned the name "QWERTY," for the first six letters on the top row of the keyboard. Only the middle row kept a semblance of the original alphabetical arrangement minus the vowels—*D F G H J K L*. Sholes's QWERTY system is still used today.



The first modern typewriter, designed by Christopher Latham Sholes, Carlos Glidden, and Samuel Soulé. (The Granger Collection, New York)

Sholes is credited with coining the name "typewriter" for his writing machine. Some researchers have suggested that part of Sholes's rationale for selecting the letters for the top line of his QWERTY keyboard was that the line then included all the letters in the word "typewriter." Salesmen demonstrating the new writing machine could show how they could type "typewriter" just using the top line of the keyboard.

The first Remington typewriters typed only capital letters. In 1878, Sholes added a shift key to his design and had both a capital and lowercase letter on each type head. His new keyboard did not have a key for the number 1, as Sholes thought that typing the small letter *L*, *l*, would suffice.

The mass production of the Remington typewriters was assigned to the treasurer of the Remington sewing machine department, H. H. Benedict. At first, the typewriter was morphed with sewing machine technology; it was mounted on a sewing machine base complete with a treadle that, when moved, returned the typewriter's carriage. The first typewriters were also festooned with the same decorative flowers that were painted on the sewing machines. It may be that the feminizing of the appearance of the first commercially produced typewriters led to the association between women and the career of typing.

Sholes spent his retirement years in Milwaukee, Wisconsin. He died on February 17, 1890, and is buried in Forest Home Cemetery in Milwaukee.

IMPACT

The typewriter has proven to be an invaluable tool since its invention and commercial production. It increased business productivity, gave writers a more rapid method for writing books and manuscripts, provided students with a means to neatly write their school papers, and gave newspaper reporters an implement for writing their articles. Perhaps the area in which it had the greatest impact was women's employment. Before the typewriter's development and subsequent demand for typists, women had few options for employment. Sholes commented several times that his invention had proved to be a blessing for women, as it enabled them to earn a decent living. Today, word processors and computers have largely replaced the typewriter, but all major computer manufacturers use Sholes's QWERTY keyboard.

—*Polly D. Steenhagen*

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See also: Chester F. Carlson; Thomas Alva Edison.

THE QWERTY KEYBOARD

Since Christopher Latham Sholes's development of the QWERTY keyboard, many others have proposed improved configurations. Because Sholes designed his keyboard to separate the most often typed pairs of letters to prevent the keys from jamming, his critics have said that the keyboard has built-in inefficiency. However, Sholes envisioned people typing with only one finger, using the "hunt and peck" method, not touch typing, which was not developed until 1888 by law clerk Frank E. McGurrin. With touch typing, the QWERTY keyboard favors use of the left hand and requires many movements of the fingers to the upper and lower levels of the keyboard. The various new keyboard designs were intended to correct the perceived inefficiencies of Sholes's keyboard.

The biggest contender for an improved keyboard was developed and patented by August Dvorak in 1936. His keyboard was touted for favoring the right hand, using the middle row keys more often than the upper and lower rows, and minimizing inefficient fingering sequences. Supporters of the Dvorak keyboard claimed that it could be learned more quickly than QWERTY and typists using it would make fewer errors.

Dvorak was a lieutenant commander in the U.S. Navy during World War II, and he convinced the Navy to allow him to perform tests on his keyboard against the QWERTY keyboard to demonstrate its superiority and to persuade the Navy to adopt his keyboard. One study had fourteen typists who averaged thirty-two words per minute on QWERTY retrain on Dvorak. After eighty-three hours of training, the participants achieved a speed of fifty-two words per minute on the Dvorak keyboard. Another of his experiments was similar, except that some of the participants could not type at all before being trained on Dvorak, thereby having no baseline to which to compare their Dvorak speeds. August Dvorak used the results of his tests to argue for the superiority of his keyboard.

Earle Strong, a professor at Pennsylvania State University, conducted less biased tests comparing QWERTY and Dvorak keyboards. He compared two groups of typists who at first all typed at the same speed, but one group used QWERTY and one Dvorak. Strong then had both groups go through skill improvement training and found the QWERTY users actually improved more than the Dvorak typists. Other studies showed that QWERTY is comparable to any of the other keyboards, including the Dvorak, and that so far no one has made a keyboard superior to Sholes's QWERTY design.

Alan Shugart

American computer engineer

Shugart helped develop the first disk drive at an IBM research laboratory in 1955, creating the digital storage industry that allowed for smaller computers that could store more data. He was also an entrepreneur, a restaurateur, and a political gadfly.

Born: September 27, 1930; Los Angeles, California
Died: December 12, 2006; San Jose, California
Also known as: Alan Field Shugart (full name)
Primary fields: Computer science; electronics and electrical engineering
Primary inventions: Floppy disk; disk drive

Early Life

Alan Field Shugart (SHEW-gahrt) was born in Los Angeles in 1930 to Donald F. and Elizabeth Shugart. His parents divorced when he was about five years old. He and his sister were raised by a single mother who taught elementary school in the farming community of Chino, California, east of Los Angeles. As a child, he exhibited an entrepreneurial spirit, partly as a result of a perceived need to support his family. He had several newspaper routes and even published a newspaper in his home. He also ran a small bicycle repair shop under a tree in his backyard. During harvest season, he worked on several area farms. His mother taught him many life lessons, including an adage: "All work and no play makes Jack a dull boy, all play and no work makes Jack unemployed."

Shugart's father, a structural engineer, remarried when the boy was quite young. While Shugart maintained a good relationship with his father, Donald spent very little time with his son. It was through one of his father's contacts that Shugart obtained a scholarship to the University of Redlands. At Redlands, he studied four different majors, but he still graduated after four years with a degree in engineering physics. The day after graduation in 1951, he started work with International Business Machines (IBM) in Santa Monica, California, as a customer engineer. He needed the job because he was married with one child.

Life's Work

By 1955, Shugart transferred to a small IBM research and development lab in downtown San Jose, California. The lab was tasked with developing technology to replace the stacks of punch cards used to store computer data. The research team of fifty people tested various methods for storing data on media such as magnetic tape and rotating drums. They settled on a design using twenty-four-inch magnetized disks stored on a rotating spindle. The data were stored on the disks using an arm, like those on record players, which also found and retrieved the data for the computer operator. Introduced on September 4, 1956, this first disk drive was called Random Access Method of Accounting and Control (RAMAC). It weighed about twenty pounds and was two feet high. IBM leased computers with the device for about $3,200 per month. It had very limited storage compared to more modern computers, but it could hold the same amount of data as fifty thousand punch cards.

In 1957, IBM promoted Shugart to a position managing a research team to build a better disk drive. His team developed a drive that had multiple arms for reading and writing data on magnetic disks. The new drive, the IBM 1301 disk storage unit, was about the same size as RAMAC but stored 50 million bytes of data. Due to the multiple reading and writing arms, it also could access the data at a much faster rate. The first 1301 disk storage units were introduced in June, 1961.

Shugart was eventually promoted to a higher management position, a promotion that required him to move to IBM's headquarters in Harrison, New York. A native and lifelong Californian, he originally refused the promotion but was told he had to take it. In 1969, after spending slightly more than a week in New York, Shugart resigned as director of engineering for the Systems Development Division of IBM. Several days after Shugart resigned, Memorex hired him and he returned to California. The company wanted him to direct an engineering division to create computer peripherals. About two hundred IBM employees followed Shugart to Memorex. In 1972, he left Memorex to start his own company, Shugart Associates. The goal of this new company was to design and build floppy disk drives to allow for more portability in data storage. By 1974, the company had no product to show investors, and it ran out of money. Shugart was asked to resign, but rather than return to the computer industry, he bought a fishing boat and opened a restaurant. He also did some consulting.

Shugart returned to data storage in 1979 with the founding of Shugart Technology, later renamed Seagate Technology. With $1.5 million in funding, the company sought to produce the first hard disk drives to be used in personal computers (PCs). In May, 1980, the company introduced a 5-megabyte, 5.25-inch disk drive. The company's first customer was Apple Computer, but in 1983 IBM included the hard disks with its PC/XT. Selling disk drives at $600 per unit, Seagate Technology earned $300 million in revenue by the end of its fifth year in operation.

In 1998, the board of directors of Seagate Technology fired Shugart as the company's chief executive officer (CEO). The firing was the result of a restructuring at Seagate in response to a downturn in the computer industry. He founded Al Shugart International, a venture capital company that invested in technology start-ups.

In addition to his work as an entrepreneurial engineer in the computer industry, Shugart worked as a political activist. In 1996, he ran his dog Ernest for a seat in the U.S. House of Representatives as a protest against the frustrating political system. He was the major financial backer of California Proposition 23 in 2000. Had it been approved by voters, the proposition would have allowed citizens the option of voting for "none of these candidates" in statewide elections. Shugart died of complications from heart surgery on December 12, 2006.

IMPACT

It is difficult to envision the widespread use of personal computers without the invention of the disk drive. When IBM introduced the first disk drive in 1956, the storage device used fifty 24-inch disks and had limited storage capacity. Almost twenty-five years later, Shugart's Seagate Technology introduced the 5.25-inch drive, and customers such as Apple Computer purchased the device for its computers sold to businesses and homes.

Though he was a pioneer in the computer industry, Shugart never accepted the word "visionary" as a descriptor. He shrugged off accolades. Some of Shugart's contemporaries called him a maverick of California's Silicon Valley. He regularly wore Hawaiian shirts to the office, and he remarked that he felt most comfortable when working on his fishing boat or at the restaurant he co-owned. Shugart's success came in part from an entrepreneurial drive that started in his youth. Guided by his mother, he learned the values of hard work, honesty, and humility. He also learned how to have fun, an important aspect of life as the CEO of a growing corporation. As a manager, he was respected by the members of his team. Shugart believed that personal relationships with customers, suppliers, and employees were important in building a successful company. He remarked that hiring people to

THE FLOPPY DISK

The floppy disk, or memory disk, as it was officially known, was introduced by International Business Machines (IBM) in 1971 and was invented by a team of IBM engineers under the direction of Alan Shugart. The disks initially were components in the Merlin (IBM 3330) disk pack file, a 100-megabyte storage device attached to IBM computers. The first floppy disks were used as the medium to store data in another device.

Early floppy disks were eight-inch flexible (hence "floppy") plastic disks coated with magnetic iron oxide. The disks were encased in a plastic housing called an envelope. One or both sides of the disk could be used for recording data. The disk was inserted into a disk drive. The drive spun the disk inside its protective envelope. The read-write head contacted the disk through an opening in the envelope. The first floppy disk created by the Shugart team could hold up to 100 kilobytes of data. Providing portability, the disk could be used to transport data from one computer to another.

In 1976, Shugart developed a floppy disk for Wang Laboratories that was only 5.25 inches. Wang wanted to use smaller floppy disks in its new desktop computers. By 1978, floppy disks could store up to 1.2 megabytes of data. Sony introduced the first 3.5-inch floppy disks in 1981. Even though these disks were housed in hard plastic, they retained the name "floppies." Despite their smaller physical size, their relative rigidity allowed them to store more data. Double-density disks stored 720 kilobytes of data while high-density disks stored 1.44 megabytes.

Floppy disks and their associated drives were gradually replaced in many personal computers by hard disk drives, also pioneered by Alan Shugart and manufactured by Seagate Technology. Early hard drives could store up to 5 megabytes of data after formatting. Similar in concept to floppy disks, hard disk drives stored data on a rigid platter connected to the computer by a data cable. Hard disks were used primarily for storage and easy access, not for moving data from computer to computer. For portability, floppy disks were eventually replaced by recordable compact discs (CDs) and digital video discs (DVDs) as well as flash drives.

Shugart's work with computer disk drives helped launch the personal computer industry. Without small, reliable, inexpensive data storage, computers would have been too large and expensive for many businesses and homes to purchase. The growth of the Internet would have been slowed without the server technology built on the advances of Shugart's work with disk drives.

staff his companies was easy and that he always tried to hire people smarter than himself.

—*John David Rausch, Jr.*

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See also: Marvin Camras; Mark Dean; Steve Jobs; An Wang.

WERNER SIEMENS

German electrical engineer

Siemens's development of diverse applications of electricity to telegraphy, combined with engineering schemes to lay underwater telegraph lines, became the basis for an international network of business contracts.

Born: December 13, 1816; Lenthe, Prussia (now in Germany)
Died: December 6, 1892; Berlin, Germany
Also known as: Ernst Werner von Siemens (full name)
Primary fields: Communications; electronics and electrical engineering
Primary invention: Telegraphy applications

EARLY LIFE

Ernst Werner von Siemens (SEE-muhnz) was born to Christian Ferdinand and Eleonore Siemens, née Deichmann, on December 13, 1816, in the Prussian town of Lenthe, near Hanover. The couple would have eight surviving boys and two daughters. The Siemens family's history could be traced back to the mid-seventeenth century Harz mountain region. By the early nineteenth century, a number of prominent individuals had left their mark in a variety of callings ranging from public service through professional careers as doctors and lawyers. Werner's father had studied agricultural science at the University of Göttingen. The generation of Werner and several of his siblings seems to have been the first to pursue educations preparing them for technical vocations.

Werner Siemens attended the Katharineum in Lübeck. He was not attracted to the traditional curriculum at this well-known school, preferring mathematics and science over humanities. He supplemented his school courses with private lessons, mainly in mathematics, and left the *Gymnasium* in 1834 without completing the final examination. He acquired training as an engineer by volunteering for military service in the Prussian Engineering Corps. After some difficulty gaining passing knowledge of subjects that had were not included in his classical *Gymnasium*'s offerings, he moved from regular service in an artillery brigade in Magdeburg to the Artillery and Engineering Academy in Berlin. There he was exposed to both theoretical and practical training under several of the best-known mathematicians and chemists of his time, including Georg Simon Ohm (1789-1854), who had developed what became the standard theory of electrical conductivity that bears his name.

LIFE'S WORK

After completing his officer training in 1838, Werner returned for a short period to his family's farm near Hanover. Apparently, it was at this time that he took particular notice of his younger brother William (born in 1823), who had hopes of leaving family farming responsibilities to two other brothers (Hans and Ferdinand) to follow a career in commerce. Werner undertook to help William attend a business and trade school in Magdeburg and even offered him additional instruction in mathematics. This close association between the two young men would have a major impact on the future of the famous company that Werner founded in 1847 under the name Siemens and Halske. When Werner Siemens joined with Johann Georg Halske to found Siemens and Halske (S and H), he would be building on the importance of his own initial work in silver and gold electroplating as well as on contributions made by other well-known figures in the field of electrical engineering. These contributions included the work of his teacher Georg Ohm and Michael Faraday's formulation in 1831 of the law of electromagnetic induction.

In 1834, the year Werner Siemens entered the Berlin academy, Moritz von Jacobi (1801-1874) made history through his invention of the first electric motor. Werner's first patent using electrolytes for silver and gold electroplating was registered in 1842, just as William decided to leave the University of Göttingen to try his hand at engineering in Magdeburg. In 1843 and 1844, William visited England, where he struck a business deal with the English firm Elkington, which was interested in using Werner's electroplating process. This was the first step that would lead to a lifelong collaboration between William and Werner, as the latter's vital inventions opened business prospects not only in England but also (through the efforts of another Siemens brother, Karl) in places as far away as St. Petersburg, Russia.

Werner Siemens's work took a major new direction when he became interested in electrical telegraphy, a new field first pioneered by André-Marie Ampère in the 1820's. By 1837, the Englishman Sir Charles Wheatstone (1802-1875) had advanced Ampère's work by inventing a pointer telegraph. Early systems sent electric current to magnetic needles at the end of a system of wires, causing the needles to indicate letters of the alphabet. Even though Wheatstone achieved higher levels of efficiency by using direct-current batteries and electromagnetic devices, his telegraph was unwieldy, given that five needles were used.

By 1847, Siemens had developed significant improvements over such early telegraphic techniques, and he succeeded in inviting Halske, head of a precision equipment company, to leave his firm to form Siemens

THE SIEMENS UNIT

Although the name Siemens is most commonly associated with the company originally founded by Werner Siemens, those familiar with special nomenclature used by electrical engineers associate the same name with the Siemens unit. Siemens developed this measurement of electrical conductance in 1860. It was initially termed the *mho*, the reverse order of letters signifying its relevance to the earlier work of Georg Simon Ohm, who in the 1820's pioneered methods of measuring electrical resistance. What Siemens aimed at in carrying Ohm's calculations forward was to determine how easily electricity flows through each segment of a potentially very complex path carrying an identifiable input, or voltage. Different levels of resistance in such a path will vary depending on, for example, materials used in each stage, from the source of electric charge to the "final destination" of the current.

Eventually, the term "Siemens unit" would be used widely in calculations relating to electrical current, whereas *mho* is now reserved for electronic applications. Despite its widespread use by electrical engineers for several generations (using as its symbol the Greek letter omega, ω, turned upside down), actual official designation of the symbol SI and adoption of the Siemens unit by the General Conference on Weights and Measures came in 1971. The Siemens unit allows calculation of the conductance of a given electrical device by a quite simple formula. Siemens defined the value of his unit of resistance (which is about .953 ohm) based on the resistance of a mercury column one meter long and one square millimeter in cross section at 0 degree Celsius. One Siemens unit of conductance would occur when one volt of electric current produces one ampere, or electric charge measured in coulombs per second. Added (or decreased) voltage in actual testing of electrical devices allows precision calculation of conductance in terms of multiples of, and fractions of, the Siemens unit. In the simplest of terms, and using integral numbers, increasing electrical voltage by one unit (one volt) produces one added ampere of electrical current. When any electrical apparatus, whether a simple household appliance or a very powerful machine, is being designed for production, use of the Siemens unit is essential in order to avoid dangerous overloading of current at any point in the circuits carrying electricity through the particular apparatus.

and Halske, headquartered in Berlin. Siemens had the rare advantage at the time of dividing his efforts between finishing the last year of his military service obligation (which involved participation in the Prussian Telegraph Commission) and the task of founding a new private company. Within a year, despite the wave of political disturbances that struck many areas of Europe, especially the German region in 1848, S and H was awarded a contract to build (in the short span of one year) Europe's first region-to-region electric telegraph, between Berlin and Frankfurt am Main. By this date, two other Siemens brothers—Karl and Friedrich—had joined Werner and William in what was becoming a broad family business enterprise.

In 1850, the year in which Friedrich became director of S and H activities in England, a significant breakthrough in international communications occurred that would have a major impact on the direction of the firm's research: The first submarine telegraph cable was laid from England to France, under the English Channel. This feat was accomplished only after an essential technical issue had been addressed: encasement of bundles of electric wires in an insulated sheath made out of latex produced from the sap of the Southeast Asian gutta-percha tree. This natural latex substance, which had been used to insulate electric cables since the mid-1840's, was superior to (unvulcanized) rubber because it did not become brittle when exposed to different temperature levels. An equally important characteristic of natural latex was its chemical composition, which actually repulsed marine plants and animals—the main cause of damage to earlier submarine cables.

By the time of Werner Siemens's marriage in 1852 to Mathilde Drumann, daughter of a Königsberg professor and mother to two children by Siemens (Arnold, born in 1853; William, in 1885), S and H had begun to expand its telegraph construction services to Russia. Activities that started with a telegraph line from St. Petersburg to Moscow in 1851 were followed by the appointment of Karl Siemens to oversee the first stages of a larger project: construction of the Russian state telegraph network. Russia's involvement in the Crimean War (against Britain, France, and the Ottoman Empire) in 1853-1856 increased the importance of S and H's work, leading to the establishment of a company subsidiary in St. Petersburg.

Despite what might have seemed a shift in "business loyalties," in 1859 Werner and William Siemens welcomed an offer from London naming them the primary submarine telegraph advisers to the British government. Their contribution to British strategic interests was already taking shape when the first telegraph line to India was completed in 1860: The imperial government would soon assume full political responsibility for India and sought to increase the efficiency of communications that would come with the opening of the Suez Canal in 1869. By 1868, Werner was engaged in construction of a state-of-the-art Indo-European telegraph line from London to Calcutta, completed in 1870.

In the meantime, S and H faced its first serious setback in 1864, only a year after establishing the first Siemens cable factory in Woolwich, England. The firm lost half its capital when it failed to complete a contract with the French government to lay a cable (using its own materials) from the coast of Spain to Algeria. This setback played a role in Halske's decision to end his participation in the English subsidiary of the company, which was restructured under the name Siemens Brothers. Halske retired from the internal direction of S and H in 1867.

During the 1870's, the Siemens company would rank among the top contractors involved in laying long-distance underwater telegraph cables. The zenith of its accomplishments in this field came in 1875, when the transatlantic cable linking Ireland to the United States was inaugurated. By this date, however, results of research undertaken by Werner Siemens and several of his colleagues at S and H pointed to new directions for the company. Siemens's long-standing interest in electric motors would be applied to electrical transport systems, a branch of company operations launched in 1879, when the company's model for an electric railway system powered by an external source of current was unveiled at the Berlin Industrial Exhibition. This new technology was put to work as early as 1881, when the first electric tramway built by Siemens began operations in the suburbs of Berlin. Soon after this, the company proved that large electrical locomotives pulling heavy loads could increase efficiency in the German coal mining industry.

Beyond his activities in the Siemens company, Werner also had a publicly recognized career. He voiced strong support for the emerging field of electrical engineering by urging introduction of this subfield as part of the curriculum in all German technical universities. From 1862 to 1866, he was an elected member of the Prussian parliament, and he helped cofound the German Progressive Party. Although his opinions led to disagreements (and withdrawal from politics) in the politically charged years that led to the founding of the German Empire (in 1870-1871), he continued to receive public recognition from the highest institutions of the new empire.

In 1873, he became a member of the prestigious Royal Prussian Academy of Sciences in Berlin, and fifteen years later Kaiser Friedrich III raised him to the ranks of the Prussian nobility (thus adding the noble particle "von" to his surname). One year before Werner handed the direction of S and H over to his brother Karl and his two sons, Arnold and William (in 1890, two years before his death), a second giant responsible for the expanding use of electricity both in domestic life and in industry shared a personal meeting with Siemens in Berlin—Thomas Alva Edison.

IMPACT

It is difficult to determine whether Siemens's impact should be measured in terms of the technical advances made possible by his discoveries or in terms of the development of the firm he founded, which became a world leader in the field of electronics. Just in terms of the expanding volume and diversity of the company's activities only a few years after his death, one could have predicted that the Siemens company was going to count among the top international firms in the twentieth century. The rapidly changing electrical and electronic advances of that century would, of course, pose new parameters for the company's activities. World demand for more and more sophisticated applications in electronics became so extensive that none of the founding members of the Siemens family could have imagined how important their company would become.

In the thirty-year period from 1872, when S and H had 1,386 employees (a large number for that time), to 1902, the company's workforce (including several subsidiaries) grew to more than 25,000. By 1872, the company was selling its products in fourteen European countries and in North and South America. By the end of the century, two new zones of operations—Australia and Africa—had been added. By 1900, Siemens was distributing an impressive range of products throughout the world. These included not only telephonic and telegraphic equipment but also cables, incandescent lamps, and dynamos.

—*Byron Cannon*

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See also: William Fothergill Cooke; Thomas Alva Edison; Michael Faraday; Samuel F. B. Morse; Charles Wheatstone.

IGOR SIKORSKY

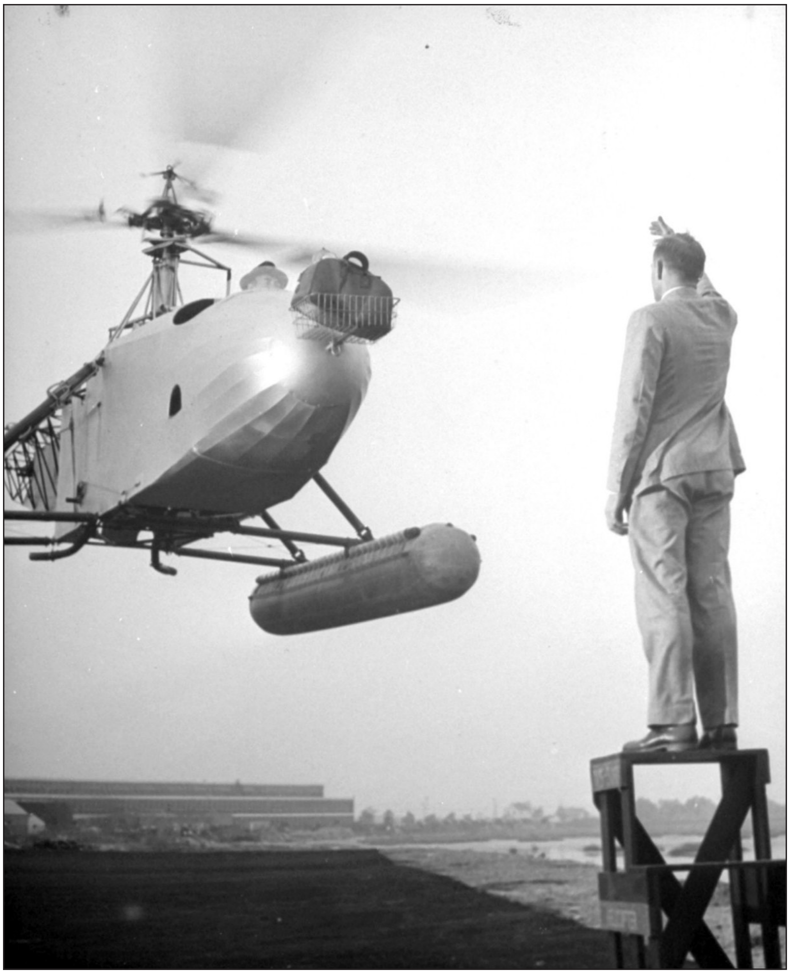
Russian American aerospace engineer

Igor Sikorsky made pioneering contributions to the design of aircraft in Russia and then in the United States, designed and flew the world's first multiengine fixed-wing aircraft, and was instrumental in the development of the helicopter industry.

Born: May 25, 1889; Kiev, Russia
Died: October 26, 1972; Easton, Connecticut
Also known as: Igor Ivanovich Sikorsky (full name)
Primary fields: Aeronautics and aerospace technology; manufacturing
Primary inventions: Helicopter; multiengine fixed-wing aircraft

EARLY LIFE

Igor Sikorsky's (EE-gohr sih-KOHR-skee) father, Ivan Alexis Sikorsky, was a professor of psychology at the University of Kiev, and his mother, Mariya Stefanovna,



Igor Sikorsky, left, takes off in the VS-300, the first practical helicopter. (Time & Life Pictures/Getty Images)

was a physician who did not practice professionally. The youngest of five children, Sikorsky grew up in Kiev, attended the Russian Naval Academy in St. Petersburg, studied engineering in Paris, and returned to Kiev to enroll in the Polytechnic Institute in 1907. Inspired by Count Ferdinand von Zeppelin's flights in his first dirigibles in Germany as well as the Wright brothers' flights at about the same time, Sikorsky returned to Paris, then the aeronautical capital of Europe. His mother had home-schooled Igor, and she developed in him a great love of art, including the life and work of Leonardo da Vinci and the fantastic stories of Jules Verne.

By the age of twelve, Sikorsky had made a small rubber band-powered helicopter, and by twenty he had built his first helicopter, although it never left the ground. Undiscouraged, Sikorsky turned his attention to fixed-wing aircraft; his second design, the S-2, was successful, and later, the S-5 won national recognition when Sikorsky flew it for thirty minutes at seventy miles per hour. The S-6A soon followed, and it won first place at the 1912 Moscow Aviation Exhibition. His success led him to be named head of the aviation division of the Russian Baltic Railroad Car Works, where he designed and built the S-21, "The Grand," the world's first successful four-engine plane. Sikorsky was the test pilot for its maiden flight on May 13, 1913. This accomplishment led to the design of an even bigger aircraft, the Ilia Mourometz, and more than seventy versions of this plane were built for use as bombers during the World War I.

The Bolshevik Revolution of 1917 disrupted life in Russia and prompted Sikorsky to leave. He first moved to France, where he began designing bombers for the Allied war effort, but the Armistice that ended World War I was signed soon after he arrived in France. Sikorsky left for the United States, arriving in New York on March 30, 1919.

LIFE'S WORK

Sikorsky struggled for several years to gain a foothold in the United States. Finally, on March 23, 1923, the Sikorsky Aero Engineering Corporation was formed in New York, with the help of friends who knew his talents, and Sikorsky began his aviation career all over again. On a chicken farm on Long Island, using spare parts and handmade tools, Sikorsky and his colleagues designed and built the twin-engine, fourteen-passenger S-29A (the *A* stood for "America") in 1924. This first prototype was made possible only because of a last-minute contribution of $5,000 from the famous Russian pianist and composer Sergei Rachmaninoff. This original S-29A was later sold to Howard Hughes, who used the plane in his early aviation epic, *Hell's Angels*, in 1930.

Sikorsky's first important commercial success was the design of the twin-engine S-38 amphibian plane in 1928. Orders soon rolled in, most notably from Pan

American World Airways (Pan Am), which used the plane to open air routes to Central and South America, and the Sikorsky Corporation moved its headquarters to Stratford, Connecticut, and continued production of the S-38. In the same year, the company became a subsidiary and then a division of United Aircraft Corporation (later known as United Technologies Corporation). Its next model was the four-engine S-40 and then the S-42, with engines built by nearby Pratt and Whitney, the "flying boat" used by Pan Am to pioneer transoceanic flights across the Atlantic and the Pacific. The S-44, developed at the end of the 1930's, was the last fixed-wing aircraft built by Sikorsky.

Having succeeded in careers designing and building aircraft in both Russia and the United States, Sikorsky now returned to his first love, helicopters, which he had tried unsuccessfully to build nearly thirty years before. On September 14, 1939, he piloted his VS-300 a few feet off the ground in a demonstration of the first practical helicopter design. By 1940, the VS-300 (for "Vought-Sikorsky," a joint venture of two divisions of United Aircraft) had become the first of the single-rotor configuration that would emerge in the future as the world standard in helicopter design. On May 6, 1941, the VS-300 set a world endurance record of over an hour and a half in the air, again with Sikorsky at the controls. Military contracts followed the success of the VS-300, and by 1943 large-scale manufacture of the Sikorsky R-4 made it the world's first mass-produced helicopter. Thus, the helicopter industry—and the helicopter age—was born.

Sikorsky continued to be a vital part of the company even after his 1957 retirement at the age of sixty-eight, and he was at his desk at the Sikorsky plant, on the Housatonic River at the Merritt Parkway in Stratford, on the day before his death at the age of eighty-three. He was buried not far from the plant, in Easton. A short-lived marriage in Russia had produced a daughter, Tania, and Sikorsky's marriage to another Russian émigré, Elizabeth Semion, in 1924 produced four sons. Their eldest, Sergei, continued in the aviation field, eventually becoming a vice president at Sikorsky Aircraft.

Sikorsky won numerous awards during his lifetime, and he is enshrined in both the International Aerospace and the Aviation Halls of Fame. In addition to his multiple aviation careers, Sikorsky produced three books. His autobiography, *The Story of the Winged-S* (1938), chronicled his development as an aircraft designer and builder, and his two religious works, *The Message of the Lord's Prayer* (1942) and *The Invisible Encounter* (1947), revealed his more spiritual side.

THE HELICOPTER

Of all Igor Sikorsky's achievements, none was more important than his development of the helicopter. Humans had dreamed of the helicopter—a craft that could move vertically without forward speed—from as far back as the Renaissance, when the notebooks of Leonardo da Vinci showed an early helicopter design. It was Sikorsky, as much as any man, who made that form of flight possible. It is noteworthy that Sikorsky was always proudest of his role in this development of an aircraft that would be so important in saving lives, in peacetime as in war, on land and on sea. The first recorded mercy mission by helicopter occurred on January 3, 1944, when a Coast Guard helicopter braved a snowstorm to get blood plasma to crewmen badly burned in an explosion aboard a U.S. destroyer off the New Jersey coast. A year later, it was a helicopter that was used to make the first wartime rescue of three British commandos and their American medevac pilot behind Japanese lines in Burma. Since that time, hundreds of thousands of people have been rescued thanks to helicopters, and the account of every national or international disaster is highlighted by images of the arrival of helicopters, plucking people from floods or storms, off rooftops or out of trees.

If anyone can be credited with that success, it would be Igor Sikorsky. He pioneered the single-rotor configuration that would become the standard world helicopter design, a rotorcraft with a single controlled-pitch, three-blade main rotor and a smaller vertical tail rotor to counteract the torque of the main rotor. His first flight of the VS-300 in 1939—a machine powered by a 65-horsepower (50-kilowatt) engine with Sikorsky sitting in an exposed pilot's seat—would lead to the rapid development of the helicopter during and after World War II, eventually producing crafts like the Sikorsky "flying cranes," the cargo helicopters used to carry heavier loads (such as trucks and prefab houses). Under his direction, Sikorsky laboratories developed numerous high-lift and control devices for this and other aircraft.

No one person invented the helicopter. It evolved from the contributions of hundreds of inventors and aeronautical engineers over decades, but only Sikorsky had all the engineering skills to develop this amazing craft, the entrepreneurial skills to bring it to production, and the spiritual vision to understand its importance.

IMPACT

Sikorsky had three almost separate careers, in Russia and the United States, and his impact on aviation history is immeasurable. As a scientist, engineer, pilot, and aircraft manufacturer, he influenced the design and development of both fixed-wing aircraft and helicopters. In a career spanning more than six decades, Sikorsky designed and flew the first four-engine airliners, developed the airplanes that would open the world to air travel, and drafted the first practical helicopter design and helped to launch the helicopter age in the United States. His accomplishments would change the faces of both war and peace. His designs for bombers altered the way warfare would be conducted from World War I on, his design of transoceanic aircraft opened up the world for travel and business, and his development of the helicopter changed the nature of flight and the pace and speed of modern life.

Sikorsky was awarded more than eighty honors during his lifetime, including the National Medal of Science presented in 1967 by President Lyndon B. Johnson, and the Royal Aeronautical Society of England's Silver Medal. The achievements of Igor Sikorsky and Sikorsky Aircraft take more than seven pages to list, and they include more than 120 firsts, from the world's record for flight duration in the S-21 in Russia, to the first airmail service between the United States and Panama (in an S-38 piloted by Charles Lindbergh), to the first helicopter (the S-55) to fly across the Atlantic Ocean (1955), to the first helicopter (the S-58) to retrieve a U.S. astronaut, Commander Alan Shepard, America's first man in space. No one has had a greater impact in a wider range of aeronautical fields.

—*David Peck*

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See also: Emile Berliner; George Cayley; Leonardo da Vinci; Andrei Nikolayevich Tupolev; Sheila Widnall; Wilbur and Orville Wright; Ferdinand von Zeppelin.

Isaac Merrit Singer

American machinist

While Singer did not invent the sewing machine, he made improvements to the machine that made it more practical and adaptable for home use. He then, through clever marketing and the first installment payment plan, made a fortune selling his machines around the world.

Born: October 27, 1811; Pittstown, New York
Died: July 23, 1875; Torquay, Devon, England
Also known as: Isaac Merrit
Primary field: Manufacturing
Primary invention: Sewing machine improvements

Early Life

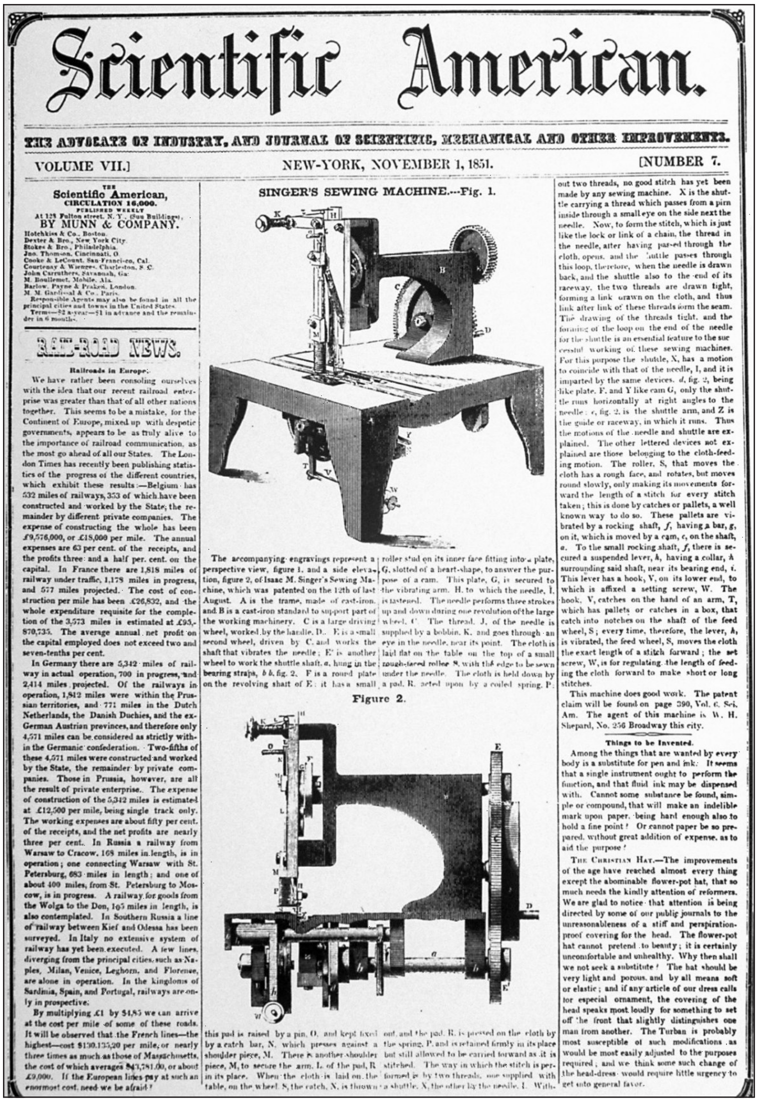
Isaac Merrit Singer was the youngest child of Adam Singer and Ruth Benson. Adam was a German immigrant from Saxony who had changed his surname from Reisinger to Singer. When Isaac was ten years old, his parents divorced and his father remarried. Isaac did not get along with his new stepmother, so at the age of twelve he left home. At first, the young Singer lived with his older brother in Oswego, New York, and worked in his brother's machine shop. It was there that he learned the machinist's trade.

In 1830, Singer married Catharine Maria Haley, and the newlyweds moved to New York City to live with her parents. Then, in the summer of 1833, the couple moved to Fly Creek in Otsego County, New York, where Singer went to work in a machine shop owned by George Pomeroy. After the birth of his first son, William, Singer moved his family back to New York City and found employment in a press shop.

Singer had long been interested in acting, and in 1836 he left his family and joined a company of traveling players. When they went to Baltimore, Singer met eighteen-year-old Mary Ann Sponseler. The next year, Mary Ann gave birth to his son Isaac while Catharine bore him a daughter, Lillian. Singer lived with Mary Ann in Baltimore, his marriage to Catharine effectively over, but he and his wife did not divorce until 1860.

Life's Work

In 1839, Singer received his first patent for a rock-drilling machine that he developed while working with one of his older brothers digging the Illinois waterway. He sold the patent for $2,000. He used the money to form his own acting company, which he called the Merrit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THE ADVOCATE OF INDUSTRY, AND JOURNAL OF SCIENTIFIC, MECHANICAL AND OTHER IMPROVEMENTS.

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RAIL-ROAD NEWS.

Railroads in Europe.

We have rather been consoling ourselves with the idea that our recent railroad enterprise was greater than that of all other nations together. This seems to be a mistake, for the Continent of Europe, mixed up with despotic governments, appears to be as truly alive to the importance of railroad communication, as the most go ahead of all our States. The London Times has recently been publishing statistics of the progress of the different countries, which exhibit these results:—Belgium has 532 miles of railways, 353 of which have been constructed and worked by the State; the remainder by different private companies. The expense of constructing the whole has been £9,576,000, or £18,000 per mile. The annual expenses are 63 per cent. of the receipts, and the profits three and a half per. cent. on the capital. In France there are 1,818 miles of railway under traffic, 1,178 miles in progress, and 577 miles projected. The cost of construction per mile has been £26,832, and the whole expenditure requisite for the completion of the 3,573 miles is estimated at £95,870,735. The average annual net profit on the capital employed does not exceed two and seven-tenths per cent.

In Germany there are 5,342 miles of railway in actual operation, 700 in progress, and 2,414 miles projected. Of the railways in operation, 1,812 miles were within the Prussian territories, and 771 miles in the Dutch Netherlands, the Danish Duchies, and the ex-German Austrian provinces, and therefore only 4,571 miles can be considered as strictly within the Germanic confederation. Two-fifths of these 4,571 miles were constructed and worked by the State, the remainder by private companies. Those in Prussia, however, are all the result of private enterprise. The expense of construction of the 5,342 miles is estimated at £12,500 per mile, being single track only. The working expenses are about fifty per cent. of the receipts, and the net profits are nearly three per cent. In Russia a railway from Warsaw to Cracow, 168 miles in length, is in operation; one connecting Warsaw with St. Petersburg, 683 miles in length; and one of about 400 miles, from St. Petersburg to Moscow, is in progress. A railway for goods from the Wolga to the Don, 105 miles in length, is also contemplated. In Southern Russia a line of railway between Kief and Odessa has been surveyed. In Italy no extensive system of railway has yet been executed. A few lines, diverging from the principal cities, such as Naples, Milan, Venice, Leghorn, and Florence, are alone in operation. In the kingdoms of Sardinia, Spain, and Portugal, railways are only in prospective.

By multiplying £1 by $4,85 we can arrive at the cost per mile of some of these roads. It will be observed that the French lines—the highest—cost $130.135,20 per mile, or nearly three times as much as those of Massachusetts, the cost of which averages $43,781.00, or about £9,000. If the European lines pay at such an enormous cost, need we be afraid?

SINGER'S SEWING MACHINE.—Fig. 1.

The accompanying engravings represent a perspective view, figure 1, and a side elevation, figure 2, of Isaac M. Singer's Sewing Machine, which was patented on the 12th of last August. A is the frame, made of cast-iron, and B is a cast-iron standard to support part of the working machinery. C is a large driving wheel, worked by the handle, D. E is a small second wheel, driven by C, and works the shaft that vibrates the needle; E' is another wheel to work the shuttle shaft, *a*, hung in the bearing straps, *b b*, fig. 2. F is a round plate on the revolving shaft of E; it has a small roller stud on its inner face fitting into a plate, G, slotted of a heart-shape, to answer the purpose of a cam. This plate, G, is secured to the vibrating arm, H, to which the needle, I, is fastened. The needle performs three strokes up and down during one revolution of the large wheel, C. The thread, J, of the needle is supplied by a bobbin, K, and goes through an eye in the needle, near its point. The cloth is laid flat on the table on the top of a small rough-faced roller S, with the edge to be sewn under the needle. The cloth is held down by a pad, R, acted upon by a coiled spring, P;

Figure 2.

this pad is raised by a pin, O, and kept fixed by a catch bar, N, which presses against a shoulder piece, M. There is another shoulder piece, M, to secure the arm, L, of the pad, R in its place. When the cloth is laid on the table, on the wheel S, the catch, N, is thrown out, and the pad, R, is pressed on the cloth by the spring, P, and is retained firmly in its place but still allowed to be carried forward as it is stitched. The way in which the stitch is performed is by two threads, one supplied with a shuttle, X, the other by the needle, I. Without two threads, no good stitch has yet been made by any sewing machine. X is the shuttle carrying a thread which passes from a pirn inside through a small eye on the side next the needle. Now, to form the stitch, which is just like the lock or link of a chain, the thread in the needle, after having passed through the cloth, opens, and the shuttle passes through this loop, therefore, when the needle is drawn back, and the shuttle also to the end of its raceway, the two threads are drawn tight, forming a link drawn on the cloth, and thus link after link of these threads form the seam. The drawing of the threads tight, and the forming of the loop on the end of the needle for the shuttle is an essential feature to the successful working of these sewing machines. For this purpose the shuttle, X, has a motion to coincide with that of the needle, I, and it is imparted by the same devices, *d*, fig. 2, being like plate, F, and Y like cam G, only the shuttle runs horizontally at right angles to the needle; *e*, fig. 2, is the shuttle arm, and Z is the guide or raceway, in which it runs. Thus the motions of the needle and shuttle are explained. The other lettered devices not explained are those belonging to the cloth-feeding motion. The roller, S, that moves the cloth has a rough face, and rotates, but moves round slowly, only making its movements forward the length of a stitch for every stitch taken; this is done by catches or pallets, a well known way to do so. These pallets are vibrated by a rocking shaft, *f*, having a bar, *g*, on it, which is moved by a cam, *c*, on the shaft, *a*. To the small rocking shaft, *f*, there is secured a suspended lever, *h*, having a collar, *h* surrounding said shaft, near its bearing end, *i*. This lever has a hook, V, on its lower end, to which is affixed a setting screw, W. The hook, V, catches on the hand of an arm, T, which has pallets or catches in a box, that catch into notches on the shaft of the feed wheel, S; every time, therefore, the lever, *h*, is vibrated, the feed wheel, S, moves the cloth the exact length of a stitch forward; the set screw, W, is for regulating the length of feeding the cloth forward to make short or long stitches.

This machine does good work. The patent claim will be found on page 390, Vol. 6, Sci. Am. The agent of this machine is W. H. Shepard, No. 256 Broadway this city.

Things to be Invented.

Among the things that are wanted by every body is a substitute for pen and ink. It seems that a single instrument ought to perform the function, and that fluid ink may be dispensed with. Cannot some substance be found, simple or compound, that will make an indelible mark upon paper, being hard enough also to hold a fine point? Or cannot paper be so prepared, without great addition of expense, as to aid the purpose?

The Christian Hat.—The improvements of the age have reached almost every thing except the abominable flower-pot hat, that so much needs the kindly attention of reformers. We are glad to notice that attention is being directed by some of our public journals to the unreasonableness of a stiff and perspiration-proof covering for the head. The flower-pot hat cannot pretend to beauty; it is certainly uncomfortable and unhealthy. Why then shall we not seek a substitute? The hat should be very light and porous, and by all means soft or elastic; and if any article of our dress calls for especial ornament, the covering of the head speaks most loudly for something to set off the front that slightly distinguishes one man from another. The Turban is probably most susceptible of such modifications as would be most easily adjusted to the purposes required; and we think some such change of the head-dress would require little urgency to get into general favor.

The November 1, 1851, cover of Scientific American *detailing Isaac Merrit Singer's improved sewing machine.* (Time & Life Pictures/Getty Images)

THE SEWING MACHINE

Several inventors worked on developing sewing machines; Isaac Merrit Singer incorporated many of their ideas and designs into his functional model. The first patent for a sewing machine design was issued in 1790 to a British inventor, Thomas Saint. He never built a working model of his design. The first working model was invented by Barthélemy Thimonnier, a French tailor. He patented a machine in 1830 that sewed a chain stitch in a straight line. In 1841, Thimonnier's factory sewed French military uniforms using eighty of his machines, but the building was destroyed by a mob of angry French tailors who thought their jobs were being threatened by mechanized sewing.

These early machines used a chain stitch, which was formed using either one or two threads. The first or only thread passed through an eye in a needle, and if there was a second thread, it moved back and forth over the fabric carried by a looper. Either way, the machine formed a series of linked loops that looked much like a chain. The major drawback of this stitch is that if the thread is broken, the chain easily unravels, much in the way a stocking will run if one thread is broken. This stitch, however, is still used today in applications such as sewing together the tops of large sacks that hold seed, grain, or dog food. The stitch keeps the bags closed but allows for quick and easy opening by just pulling the thread.

Walter Hunt developed the lockstitch in 1834, using a thread on a curved needle that passed through fabric horizontally, thus forming a loop on the underside of the fabric. A shuttle then passed another thread through this loop, locking the stitch. It is much more difficult to rip out a seam sewn with a lockstitch, so the seams in clothing sewn in this way will not unravel. Howe sold his machine without patenting it. Elias Howe then produced and patented a machine very similar to Hunt's in 1845.

Singer's machine combined design features of these first machines. He added a presser foot to anchor the fabric being sewn in place, a tensioning system to adjust the tension of the thread for sewing different weight fabrics, and a fixed arm to hold the sewing needle vertically. Some of the earlier machines were operated with a hand crank, but Singer used a foot treadle that left the sewer's hands free to manipulate the fabric. The machine as designed by Singer remained the standard until 1889, when the Singer Sewing Company introduced electric machines. At this point, however, the electric model was simply the same design, but with an electric motor attached to the side to turn the sewing wheel.

Players. He and Mary Ann, who now went by the names of Isaac Merrit and Mrs. Merrit, toured for five years until their money ran out. The couple eventually had ten children together.

When his money ran out, Singer found himself in Fredericksburg, Ohio, where he found employment in a print shop. His work inspired him to design a machine to cut wood and metal printing blocks. He moved on to Pittsburgh, Pennsylvania, where on April 10, 1849, he patented his machine for carving wood and metal. He then moved back to New York City and built a working prototype of his machine at A. B. Taylor and Company, but when the shop's boiler exploded, his machine was destroyed. Orson C. Phelps heard about Singer's machine and asked him to come to Boston and build another one.

While there, Phelps asked Singer if he could improve the Lerow and Blodgett sewing machines that were being manufactured at Phelps's shop. At first, Singer refused, thinking the machine mundane and beneath him, but he eventually agreed. In eleven days, Singer was able to make over the difficult, impractical machine. Singer patented his new design (patent number 8,294) on August 12, 1851. With financing from George B. Zieber, Singer, along with partners Zieber and Phelps, formed the Jenny Lind Sewing Machine Company, soon renamed I. M. Singer and Company.

By the time Singer filed his patent, several others had already independently developed sewing machines. Elias Howe had filed for a patent for his machine on September 10, 1846. Like Singer's machine, Howe's was an improved model of another machine—in this case, one invented by Walter Hunt. A lawsuit between Hunt and Howe was decided in Howe's favor. Subsequently, Howe sued Singer.

By 1856, Singer, Baker, Grover, Watson, and Wheeler, all sewing machine manufacturers, were each accusing the others of patent infringement. The president of the Grover and Baker Company, Orlando B. Potter, suggested that the companies would fare better by sharing their patents. Together they brought Howe into their patent pool and formed the Sewing Machine Combination. I. M. Singer and Company was now free to mass-produce machines without fear of lawsuits.

Singer now faced the task of creating a market for his machines. Up to this point, sewing machines had only been used commercially by tailors and harness makers. Singer embarked on huge advertising campaigns aimed at housewives, and he provided an installment payment plan to make the machines affordable to all. I. M. Singer and Company manufactured and sold 2,564 machines in 1856 and built a factory in Scotland to produce machines for the European market.

Singer prospered financially, but his personal life was thorny. He moved to a mansion on Fifth Avenue in New York City with Mary Ann and their children, and in 1860 he divorced Catharine, accusing her of adultery. However, in 1862, when Mary Ann discovered that Singer had started another family with Mary McGonigal, with whom he now had five children, Mary Ann had him arrested for bigamy. Singer, disgraced, moved with McGonigal to London. Later, a fourth wife and daughter, Mary Eastwood Walters and Alice, surfaced in New York. In Europe, Singer left McGonigal, rekindled a relationship with Isabella Eugenie Boyer, and married her, pregnant, in 1863. They moved to Paris and eventually had six children.

In 1863, the I. M. Singer and Company was disbanded and then reorganized as the Singer Manufacturing Company. Singer continued to be a major stockholder, but he no longer was involved with the company's operation. Singer later moved back to England with Isabella and built Oldway Mansion in Paignton. He died there in 1875 and was buried in the Torquay Cemetery.

IMPACT

In many ways, Singer is the epitome of the nineteenth century American self-made man. Born into an impoverished, immigrant family and on his own at age twelve, Singer learned the machinist's trade through his various odd jobs while pursuing his love of acting. Singer had the uncanny abilities to look at a need for a machine or an existing but impractical device and see how to design or improve it, to be at the right place at the right time, to surround himself with lawyers and financial bankers who could help him achieve his goals, and to use his ingenuity to develop the installment plan and his flair for the dramatic to sell his product.

While Singer did not invent the sewing machine, he improved it so that it could be used reliably and be manufactured at a reasonable cost. These two qualities made it practical to sell the machine to housewives and thus revolutionized sewing in America. The sewing machine could now be used both by commercial entities to sew clothing, harnesses, and even hydrogen balloons, and by domestic housewives to produce family clothing much more rapidly than by hand sewing.

—Polly D. Steenhagen

FURTHER READING

Bissell, Don. *The First Conglomerate: 145 Years of the Singer Company*. Brunswick, Maine: Audenreed Press, 1999. Written by a president of the Singer Company, this book gives the history of the development of the sewing machine by Singer, and a short biography of Singer as the first president of the company, as well as biographies of all the subsequent presidents.

Brandon, Ruth. *Singer and the Sewing Machine: A Capitalist Romance*. New York: Kodansha America, 1996. An insightful biography of Singer, whom the author portrays as a womanizing actor, who was uninterested in sewing machines except as a vehicle to personal wealth. Illustrations, index.

Carlson, Laurie. *Queen of Inventions: How the Sewing Machine Changed the World*. Brookfield, Conn.: Millbrook Press, 2003. Geared to children age ten and up, this book tells the story of Singer's "stitching machine" and explains how it revolutionized sewing. Well illustrated.

Head, Carol. *Old Sewing Machines*. Oxford, England: Shire, 2008. Discusses early sewing machines (up to the 1880's) and offers good explanations of how they work. Illustrations, index.

Parton, James. *History of the Sewing Machine*. Ann Arbor, Mich.: Scholarly Publishing Office, 2005. A reprint of Parton's book, originally published in 1872, colorfully describing the life of Elias Howe, his development of his sewing machine, and its connection with Singer. Illustrated with intriguing drawings depicting events in Howe's life.

See also: Beulah Louise Henry; Elias Howe; Jan Ernst Matzeliger.

JAMES MURRAY SPANGLER

American janitor and entrepreneur

Spangler's electric suction sweeper revolutionized household cleaning in the United States and abroad. His Electric Suction Sweeper Company became the Hoover Company, which grew to be the largest vacuum cleaner company in the world and a leader in innovative marketing techniques.

Born: November 20, 1848; Plainfield, Pennsylvania
Died: January 22, 1915; Chicago, Illinois
Primary field: Household products
Primary invention: Vacuum cleaner

EARLY LIFE

James Murray Spangler was born in Plainfield, Pennsylvania, the son of William and Elizabeth Lind Spangler. He came from a large family with five brothers and four sisters. On May 21, 1874, he married Elestra Amanda Holtz. They had three children: two sons, Clarence and Francis, and a daughter, Jennie.

In 1880, Spangler moved his family to Akron, Ohio, where he operated a men's clothing business with one of his brothers. He also worked as a salesman for the Aultman Company, which manufactured portable and traction steam engines. Interested in how things worked and how they could be improved, Spangler invented a grain harvester and a combined hay rake and tedder. He received patents for the equipment in 1887 and 1895, respectively. He then founded a company to manufacture and sell his inventions but was unsuccessful in this business venture.

Despite this setback, Spangler's interest in inventing was not dampened. His next invention was a velocipede wagon. In 1897, he received a patent for it and promptly sold his invention to a Springfield, Ohio, company. Unfortunately, about this time bicycles gained immense popularity and overshadowed the velocipede wagon, resulting in disappointing sales.

LIFE'S WORK

Eventually, Spangler took a janitorial job at the Zollinger Department Store in Canton, Ohio. He suffered from asthma, which was severely aggravated when he swept the dusty floors. Spangler became convinced that there was a better way to clean the dust and dirt from floors. Observing a rotary street sweeper in operation, he got the idea for a vacuum cleaner or, as he called it, an electric suction sweeper. Spangler attached a sewing machine motor to a carpet sweeper. He cut a hole in the back of the sweeper and attached fan blades that would blow dust into the attached sweeper bag (a pillowcase). He attached one end of a leather belt to the motor shaft and the other end to a wooden cylinder with a brush roller. He used a broomstick for a handle and a wooden box for the main body of the sweeper. Spangler's invention proved very successful, and he was ready to go back into business.

In September of 1907, he filed for a patent for his electric suction sweeper. Later that fall, he entered into a partnership with Ray Harned, the nephew of F. G. Folwell and W. H. Folwell, the owners of the building in which the Zollinger Department Store was located. Spangler and Harned named their business the Electric Suction Sweeper Company, financed by the Folwells. Spangler was granted a patent on the sweeper in June of 1908. Dissatisfied with the amount of financial backing from the Folwells, Spangler began to search for additional assistance.

Spangler soon found his investor. His first cousin was married to William Henry "Boss" Hoover, a saddle and harness manufacturer. At the time, Hoover was looking for a new product to sell. (With the invention of the automobile, demand for his leather goods was severely diminished.) Hoover's wife had bought one of Spangler's sweepers, which her husband found fascinating. Hoover promptly invested in the Electric Suction Sweeper Company, which started with just six employees who assembled the sweepers in Hoover's saddle and harness shop. By August of 1908, the company had been reorganized, with Hoover as president and treasurer and his son as secretary and general manager, with responsibility for sales and marketing. The firm was headquartered in Canton, but as early as 1911 Hoover began to expand the company by opening a factory in Canada. The first sweeper sold by the company was the Model O, which retailed for $60.

Hoover and his son were instrumental in making the electric suction sweeper a success. They developed innovative marketing techniques to convince consumers to buy this new type of sweeper. The first advertisement for the sweeper appeared in *The Saturday Evening Post* in 1908. It offered potential buyers a free ten-day in-home trial of the sweeper. The sweepers were not, however, sent directly to consumers. Instead, Hoover made them available at reputable stores, thus developing a dealer network for the product. The following year, the company placed a full-page ad in *Collier's*.

The Spangler family was still very involved in the Electric Suction Sweeper Company. Spangler became superintendent and continued to work at the company for a salary. He also received royalties for his invention. Both Spangler's wife and his daughter Jennie made all the bags for the sweepers until 1914, when that work was moved to New Berlin, Ohio. Spangler's son Clarence also worked at the company for a short time. He contracted a terminal disease and died in December, 1911. On January 22, 1915, James Spangler died in Chicago.

The company continued to prosper under Hoover. In 1919, he opened a factory in England, and in 1922 he renamed the company the Hoover Company. He continued to pay royalties to the Spangler family until June 2, 1935, when Spangler's patent expired.

Impact

Spangler's electric suction sweeper made household cleaning easier, more efficient, and healthier, as his vacuum cleaner sucked up dust and debris into a bag. Spangler played a significant role in launching the vacuum cleaner manufacturing industry with the founding of the Electric Suction Sweeper Company. William Hoover's successful marketing of the sweepers under the Hoover name in England resulted in "hoovering" becoming a synonym for "vacuuming" in British English. Spangler's invention also led to new advertising and marketing strategies, particularly in the United States. In-home demonstrations, door-to-door selling, and free home trials were introduced by the Hoover Company.

—*Shawncey Webb*

The Electric Suction Sweeper

The electric suction sweeper invented by James Murray Spangler was the first practical portable vacuum cleaner. As early as 1868, Ives W. McGaffey had invented a manually powered cleaner. It was difficult to operate, however, because the user had to turn a hand crank while pushing the device. Other types of vacuum cleaners, including a pneumatic one, were invented during the nineteenth and early twentieth centuries, but none was practical for use as a household cleaner. H. Cecil Booth's Puffing Billy was very efficient at removing dust and dirt, but it was so large that it had to be drawn by horses and parked in the street outside the building to be cleaned.

With his electric suction sweeper, Spangler solved many of the problems associated with the early vacuum cleaners. His cleaner was portable, could be used easily by one person, and had a brush roller to loosen dirt that the cleaner sucked into a bag. The first cleaner that he assembled consisted of a sewing machine motor with fan blades attached to blow dust and dirt into a pillowcase, which served as a bag. He attached the brush roller to the motor with a leather belt. The sweeper was an upright unit with a broomstick handle. The body of the prototype was a hand carpet sweeper with a hole cut in it to permit the dust and dirt to pass into the bag. He soon replaced the carpet sweeper with a wooden box. Spangler continued to improve his sweeper by improving the design. In 1908, the Electric Suction Sweeper Company introduced its first vacuum cleaner, the Model O, which had a sheet-steel body and iron castings. The sweeper was heavily decorated in the Art Nouveau style. The following year, the Senior model was introduced. It had aluminum castings and no decorations.

Although Spangler died just eight years after founding his company, the firm (renamed the Hoover Company in 1922) continued to improve its product and play a significant role in the development and manufacture of vacuum cleaners. In 1926, Hoover engineers developed the metal beater bar, which lightly struck the carpet to loosen deeply trapped dirt. This was a significant improvement to the wooden cylinder with the brush roller of the original electric suction sweeper. The company also introduced innovative designs, including the Constellation, a canister vacuum that hovered on its exhaust. Hoover was the first vacuum cleaner company to make disposable bags. The steam cleaner and the self-propelled cleaner also were first developed by the Hoover Company.

Further Reading

Gershman, Michael. *Getting It Right the Second Time: How American Ingenuity Transformed Forty-nine Marketing Failures into Some of Our Most Successful Products*. Reading, Mass.: Addison-Wesley, 1990. Includes a good discussion of what happened to Spangler's invention once Hoover began running the company. Discusses Hoover's marketing techniques for making the vacuum cleaner a success.

Ikenson, Ben. *Patents: Ingenious Inventions—How They Work and How They Came to Be*. New York: Black Dog & Leventhal, 2004. Contains a diagram of Spangler's electric suction sweeper and his description of it.

Kenney, Kimberly A. *Canton: A Journey Through Time*. Charleston, S.C.: Arcadia, 2003. An excellent history of the Hoover Company and how it became world-famous, as well as its role in the small midwestern town of Canton, Ohio.

Smil, Vaclav. *Creating the Twentieth Century: Technical Innovations of 1867-1914 and Their Lasting Impact*. New York: Oxford University Press, 2005. Spangler's electric suction sweeper is among the vast array of electrical inventions discussed.

See also: King Camp Gillette; Earl S. Tupper.

PERCY L. SPENCER

American electrical engineer

Spencer is best known as the inventor of the microwave oven, one of the most popular household time-, labor-, and energy-saving devices of the twentieth century.

Born: July 9, 1894; Howland, Maine
Died: September 8, 1970; Newton, Massachusetts
Also known as: Percy Lebaron Spencer (full name)
Primary fields: Electronics and electrical engineering; household products
Primary invention: Microwave oven

A chef prepares food with the Raytheon Radarange, the first commercial microwave oven. (Time & Life Pictures/Getty Images)

EARLY LIFE

The childhood of Percy Lebaron Spencer was one of tragedy and deprivation. He was born in a Maine farming community in 1894. His father died when he was eighteen months old, and his mother abandoned him soon afterward, leaving the young Spencer with an impoverished aunt and uncle. At age twelve, Spencer left elementary school to work in a local paper mill to bring much-needed extra income into his household. Four years later, after learning that the mill was to become electrified, he volunteered to assist with installing the electrical system, which provided him with a practical education in electrical engineering.

Inspired by reports of the efforts of wireless telegraphers to rescue victims of the *Titanic* disaster in 1912, Spencer developed an interest in radio, a technology then in its infancy. Joining the Navy as a teenager, he feigned a formal education by teaching himself from textbooks in order to gain admission to radio school. Spencer excelled as a radio engineer and was appointed supervisor of a crew of naval radio operators during World War I. Following his discharge from the Navy, Spencer went to work in the burgeoning radio industry, taking a job with the Radio Corporation of America (RCA) in 1918. In 1922, the Raytheon Company, an early manufacturer of radio components, hired Spencer at the suggestion of his brother John, an engineer with the company.

LIFE'S WORK

During his time at Raytheon, Spencer worked extensively with vacuum tubes, an essential component of early radios. In 1925, after leading radio manufacturer RCA increased the operating voltage of its radios, rendering Raytheon tubes obsolete, Spencer quickly developed a tube compatible with the new radios, saving the most profitable product manufactured by the company and

THE MICROWAVE OVEN

The small, relatively inexpensive microwave oven so familiar to Americans of the late twentieth century took decades to evolve from early prototypes. The first microwave oven, introduced by Raytheon in 1947 and dubbed the Radarange, was much too cumbersome for household use, standing over five feet tall and weighing more than 750 pounds. The device also required a constant water supply for cooling. The first Radaranges marketed to the public retailed for around $5,000 (more than $48,000 in 2008 dollars), rendering them further out of reach of the average consumer. The first Radaranges were used for cooking on ships and trains and in a small number of restaurants, as well as for other nonculinary commercial purposes such as drying paper and leather. Eventually, mass producers of food realized the potential of microwave ovens and began using them for a variety of industrial and food service applications, such as drying potato chips and roasting coffee beans and peanuts.

Realizing the potential of the microwave oven for household use, Raytheon continued to work toward manufacturing smaller and less expensive microwave ovens throughout the 1950's and 1960's as competitors entered the market. The Tappan Corporation introduced the first home microwave oven in 1952, but this model was still larger than a conventional oven and expensive—at $1,295 (around $10,500 in 2008 dollars)—and thus sold poorly. In the mid-1960's, Litton Industries, another defense contractor with experience in the manufacture of magnetrons, began marketing microwave ovens for household use utilizing a short, wide design that became an industry standard. In 1967, Amana, a subsidiary of Raytheon, introduced a household version of the Radarange with a compact design similar to that of the Litton oven, further increasing the choices available to consumers. Yet the relatively high retail prices of microwave ovens still limited their use to affluent households, and many consumers were still wary of using microwave ovens because of fears of radioactive contamination. Nevertheless, by the early 1970's, a steady decrease in prices had made microwave ovens available to a wider range of consumers. As prices continued to drop throughout the 1970's and 1980's, consumers around the world, attracted by the time- and labor-saving potential of microwave ovens, purchased them in increasing numbers. By the mid-1980's, roughly one-fourth of all American households owned a microwave oven.

By the 1990's, relaxed international trade standards and the availability of cheaper parts had lowered prices to levels far below those of conventional ovens, and American consumers enjoyed access to microwave ovens in a variety of sizes and price ranges. Fears of the potential harmful effects of microwave cooking had largely abated as decades of use yielded no discernible evidence of such effects. At the end of the twentieth century, microwave ovens were more common than conventional ovens, appearing in more than 93 percent of American households and in settings where conventional ovens were impractical, such as offices, college dormitories, and motel rooms.

facilitating Raytheon's growth during the 1920's. During the 1930's, he developed a more efficient vacuum tube for radios that helped sustain the company during the Great Depression. Driven by a seemingly insatiable curiosity, Spencer developed a reputation as a tireless worker who often spent hours in the laboratory dismantling and reassembling parts and devices to familiarize himself with their inner workings and to devise ways of improving them. Devices or materials that other engineers discarded as waste were often a source of inspiration and knowledge for Spencer, who in the course of his research discovered that broken vacuum tubes were capable of emitting large amounts of concentrated photoelectric energy, a discovery that aided the development of cathode-ray tubes for televisions in the 1930's.

During World War II, Spencer worked extensively with radar, a technology still in its experimental stages that involved long-distance detection of airplanes, artillery, and other objects through the use of concentrated electromagnetic waves fired over long distances that would reflect from the objects and reveal them as images on a display screen. The key component of these radar devices was a magnetron, a high-powered vacuum tube from which electromagnetic waves were emitted. As the war intensified, an increasingly urgent demand for the deployment of radar units in the field went unfulfilled because of the slow nature of the production process. At the behest of U.S. and British military forces, Spencer developed a method of mass-producing magnetrons through an innovative laminating process that enabled the tubes to be fashioned rapidly from thin sheets of metal. This process resulted in a dramatic increase in the use of radar units by Allied forces toward the end of the war. In the process of improving production techniques, Spencer also made several improvements to radar devices that rendered them more accurate and effective. In addition, he drew upon his knowledge of radar to develop the proximity fuse, a small radarlike device that could be placed in artillery shells to ensure their detonation at the proper distance from their targets. For his efforts, the Navy presented Spencer with its highest civilian honor, the Distinguished Public Service Award.

Spencer continued experiments with the new technology following the end of the war, winning critical peacetime defense contracts that helped to keep his company afloat during the postwar era. In 1945, Spencer, working to develop an improved radar device, conducted an experiment using a high-powered magnetron. During the experiment, he discovered that the candy bar that he was carrying in the pocket of his lab coat had melted. Intrigued, Spencer subsequently placed a quantity of popcorn in front of the magnetron and watched as it quickly popped. He later placed the magnetron inside a metal box to concentrate the waves further and placed an egg beside the box; the egg reportedly exploded in the face of his assistant as the magnetron heated it from within. Spencer had demonstrated that the radio waves capable of detecting metal objects from a distance by bouncing off them were absorbed by most nonmetallic substances, producing heat from within the substances through a process known as dielectric heating, in which microwave radiation accelerates the motion of molecules within a substance and heat is produced by friction from the contact between the molecules.

Intrigued by the promise of his initial experiments, Spencer began working toward development of a workable device for cooking food with microwave radiation. The primary obstacle to developing this device was devising a means of controlling the power emitted by the magnetron to avoid overheating the food being cooked, a problem that Spencer resolved with characteristic resolve and urgency. Having devised a suitable prototype, Spencer filed for a patent for the microwave oven on October 8, 1945. In 1947, Raytheon introduced the Radarange, the first microwave oven marketed to the public. The company paid Spencer a token fee of two dollars for rights to the patent but soon promoted him to vice president, a position that he would hold for the remainder of his life. In 1958, Raytheon honored Spencer by dedicating a research laboratory to him in Burlington, Massachusetts. Spencer Laboratory remained an active research facility until 1965 and was still owned and occupied by Raytheon at the end of the twentieth century.

The holder of more than 150 patents by the end of his career, Spencer remained active in his field following his retirement from full-time research, continuing as a vice president and senior consultant at Raytheon until his death in 1970 at age seventy-six. Many of his obituaries scarcely mentioned his invention of the microwave, citing instead his relatively obscure work in defense and vacuum tube technology. In 1999, Spencer was inducted into the National Inventors Hall of Fame.

IMPACT

Despite lacking a high school education, Spencer became recognized worldwide as one of the leading experts in microwave technology and the inventor of the most widely known and frequently used device to utilize the technology, the microwave oven. As a self-taught inventor who developed his inventions in corporate laboratories, Spencer is also symbolic of the shift in focus from the individual to the corporation that characterized technological research in the developed world during the early twentieth century. His invention of the microwave oven is an early example of the adaptation of military technology to consumer applications that would become a dominant force in the U.S. economy during the latter half of the twentieth century. By providing humans with an alternative means of preparing food, the microwave oven produced changes in cuisine, diet, and eating habits, creating demand for new products geared toward the new technology such as microwave-safe cookware and foods prepared and packaged for microwave cooking.

—*Michael H. Burchett*

FURTHER READING

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Gupta, Manoj, and Eugene Wong Wai Leong. *Microwaves and Metals*. Hoboken, N.J.: John Wiley & Sons, 2007. This microwave engineering text includes images of Spencer's original patent application, a brief discussion of the invention of the microwave oven, and an overview of practical industrial applications of microwave oven technology.

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World Report, April 7, 1997, 16. This brief historical synopsis of the microwave contains information about Spencer and the microwave oven not mentioned in similar sources.

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See also: Clarence Birdseye; Josephine Garis Cochran; Philo T. Farnsworth; Pyotr Leonidovich Kapitsa; Maria Telkes; Benjamin Thompson.

ELMER AMBROSE SPERRY

American engineer

One of the most prolific inventors in U.S. history, Sperry invented an improved gyrocompass and contributed to significant military projects in the lead-up to World War I. He also possessed the business acumen to turn his inventions into lucrative investments.

Born: October 12, 1860 (baptized); Cortland, New York

Died: June 16, 1930; Brooklyn, New York

Primary fields: Mechanical engineering; military technology and weaponry; navigation

Primary inventions: Gyrocompass; gyrostabilizer; flying bomb

EARLY LIFE

Born in Cortland, New York, Elmer Ambrose Sperry tinkered with mechanical devices from an early age. He was fascinated by the machine shops in his hometown and spent many days learning how machines worked. Recognizing the young boy's potential talents, the local YMCA sponsored Sperry on a trip to the 1876 Centennial Exposition in Philadelphia. The central feature of the exposition was Machinery Hall, a massive building filled with all the mechanical and technological achievements of America's industrial age. Amid the massive machines and whirring cogs, Sperry discovered where his future lay.

Sperry subsequently attended two years at Cortland Normal School (now State University of New York College at Cortland), followed by a year at Cornell University. At Cornell, he concentrated on electrical engineering. In 1880, he moved to Chicago, where he founded the Sperry Electric Company to manufacture dynamos and arc lamps.

LIFE'S WORK

Sperry's new firm specialized in urban lighting systems, and Sperry designed the electric street lighting for a number of large American cities, earning him a fortune in contracts. In 1887, Sperry married Zula Goodman, with whom he had four children. The next year, he established the Sperry Electric Mining Machine Company to manufacture machines for mining. After observing many American mines still using obsolete steam machinery or even brute manpower, Sperry began to design systems to electrify the mines. Starting with electric lighting to illuminate deep shafts, he followed with electric drills, hoists, and sorters that sped up the pace of production and improved safety.

Sperry next turned his attention toward electric streetcars. In 1890, he organized the Sperry Electric Railway Company, and he designed a streetcar that used electricity more efficiently and could run longer on a single charge than other models. He first sold the design to the city of Cleveland, Ohio, and other cities purchased his design after seeing its success. Sperry would continue to develop railroad technology for the rest of his life. In 1911, he established the Sperry Rail Service, which developed devices for testing railroad lines and locating rail defects to reduce accidents.

Sperry also improved on existing searchlights, using better lens design to increase their brightness without increasing their weight. The searchlight was adapted to serve as a beacon in a number of lighthouses and airfields in the early twentieth century, giving Sperry still more public exposure.

His greatest achievement came in 1911, when he received a U.S. patent for his gyrocompass, a nonmagnetic compass that indicates true north. In 1910, Sperry founded the Sperry Gyroscope Company in Brooklyn, New York, and his gyrocompass underwent its first trial in 1911, when it was installed on the U.S. battleship *Delaware*. Before Sperry's invention, ships relied on magnetic compasses. These devices do not point to true north; instead, they point to magnetic north. The true North Pole is the axis around which the Earth revolves, while the magnetic North Pole is the positive pole of the Earth's magnetic field, which is some distance from the North Pole. Thus, while magnetic compasses are generally accurate and practical for most basic purposes, they are not precise enough when speed and efficiency are of the essence.

Magnetic compasses were useful on ships made of wood, but they were practically worthless on iron ships, which appeared in the nineteenth century. The metal hull of the ship affected the magnetic field around the vessel, degrading the accuracy of the magnetic compass. Electrical systems on the ship also hampered the compass's accuracy. Sperry's compass, harnessing the gyroscope, solved the problem. The spinning gyroscope aligned itself to the spinning of the Earth, maintaining a north-south orientation. With the gyrocompass locked onto the north-south line, any relative movement could be measured to determine course direction, measured as degrees off the north-south alignment. Consequently, not only were north and south determined accurately, but relative movement east-west also was very precise.

Sperry's gyrocompass design was an improvement on German scientist Hermann Anschütz-Kaempfe's gyrocompass. When Sperry tried to sell his version to the German navy, Anschütz-Kaempfe sued Sperry for patent infringement. In 1915, a German court ruled in Anschütz-Kaempfe's favor, largely because, with World War I going on, Sperry refused to risk his life to go to Germany to defend himself. The U.S. Patent Office upheld his U.S. patent, however, and Sperry continued to produce gyrocompasses. Gyrocompasses can still be found on ships today, although satellite navigation has largely supplanted them.

Sperry found other applications for the gyroscope. In 1913, he received a patent for a gyrostabilizer, a device to control the roll, pitch, and yaw of a moving ship. Before Sperry's invention, even the largest ships were at the mercy of the sea. Sperry's gyrostabilizer was a powered gyroscope mounted in the center of the ship's hull and attached by linkages to fins mounted on the sides of the ship. At sea, the gyrostabilizer measured the movement of the hull relative to the stable gyroscope. By accurately measuring how much the ship moved, the gyrostabilizer could then actuate the external fins to dampen the roll, pitch, or yaw. The device could not completely compensate for a ship's movement, but it smoothed out the ride considerably. Moreover, as an automatic device, it acted more quickly and more precisely than could a human at the fin controls. In the 1920's, Sperry invented "Metal Mike," the first automatic pilot for ships. Sperry's autopilot allowed a ship to follow a straight course and to maintain a set speed without direct intervention. This made it easier to steer a ship because helmsmen no longer had to constantly make minute adjustments to the ship's wheel and throttle.

Like many scientists and inventors, Sperry worked on military projects during World War I. His most prominent invention was a precursor to the cruise missile. Sperry, working with his son Charles and Peter Cooper Hewitt, developed the "flying bomb," an unmanned aerial vehicle also known as an aerial torpedo. Hewitt was a pioneer in radio technology, and Sperry believed that Hewitt could provide the expertise to use radio waves to control a gyrostabilizer by remote control. Glenn H. Curtiss, the famed aircraft designer, aided with the aircraft components. After a number of failed flights in 1917, the group found success on March 6, 1918. The flying bomb flew more than half a mile under radio control and struck its intended target. Using a modified Curtiss N-9 airframe, the flying bomb flew for nearly eight miles in a test in October, 1918. However, the war ended a month later, the flying bomb project was canceled, and

THE GYROCOMPASS

Elmer Ambrose Sperry's gyrocompass consists of an electrically driven gyroscope whose wheel is mounted within two gimbal rings attached to a base. This design allows the wheel to move in any direction. Employing the principle of angular momentum, the constantly spinning wheel remains in the same location and attitude unless acted upon by an external force. The angular momentum of the device interacts with the rotational force of the Earth to maintain orientation to the north-south line. The heavy base prevents the mount from shifting and also serves to isolate the gyrocompass from any outside magnetic influence. This is one of the great weaknesses of magnetic compasses on an iron ship, whose own magnetic field throws off the compass. Isolated from magnetic force, the gyrocompass has no such interference. Also, unlike the magnetic compass, the gyrocompass points to true north rather than magnetic north, a crucial feature for precise navigation.

Other factors that might affect a magnetic compass—electricity, inert metals, or the temperature of the device—have no effect on the gyrocompass. An electric motor powers the gyrocompass to ensure that the wheel continues spinning, and a metal housing usually covers the gyrocompass to prevent any outside effect on the gyroscope. Its tolerance for all types of weather makes the gyrocompass a popular means of navigation in many hostile environments.

the world would have to wait for the emergence of the cruise missile. The project got Sperry interested in automatic control for airplanes, and he developed several basic designs based on his ship autopilots. Sperry was still working on the project when he died in 1930 at the age of sixty-nine.

Impact

During his lifetime, Sperry founded eight companies and received some four hundred patents. His inventions made rail and sea travel safer, opening the world for exploration by common people. Many of his inventions, including his autopilot designs, utilized gyroscopic principles. His most famous invention, the gyrocompass, was used by Allied navies during the two world wars. In his will, Sperry left a large portion of his estate to the YMCA, the organization that opened his eyes to the future of mechanical engineering.

—*Steven J. Ramold*

Further Reading

Brown, David E. *Inventing Modern America: From the Microwave to the Mouse*. Cambridge: MIT Press, 2002. An homage to American inventors of the twentieth century, this book places Sperry within the context of developmental inventions, revealing how earlier inventions shaped Sperry's work and how Sperry's invention of the gyrocompass in turn influenced inventors after him.

Fahrney, D. S. *The History of Pilotless Aircraft and Guided Missiles*. Washington, D.C.: Department of Navy, Bureau of Aeronautics, 1958. The only significant study of Sperry's World War I efforts to create a guided weapon, the book attempts to demonstrate that the true origins of guided weapons began in the United States, not Germany, with its infamous V-1 and V-2 rockets.

Hughes, Thomas Parke. *Elmer Sperry: Inventor and Engineer*. Baltimore: The Johns Hopkins University Press, 1993. The only general biography of Sperry ever written, this book concentrates on the whole spectrum of Sperry's career. Hughes does not focus on any particular invention or period of Sperry's life.

See also: Glenn H. Curtiss; Charles Stark Draper; Léon Foucault; Peter Cooper Hewitt.

Frank J. Sprague

American electrical engineer

Often called the "father of electric traction" for his development of the first commercially successfully electric railway system, Sprague was also well known for his inventions related to the electric elevator and the multiple-unit system of automatic control of electric railways.

Born: July 25, 1857; Milford, Connecticut
Died: October 25, 1934; New York, New York
Also known as: Frank Julian Sprague (full name)
Primary field: Electronics and electrical engineering
Primary inventions: Electric elevator; electric motor; electric traction system

Early Life

Frank Julian Sprague (sprayg) was the second of three sons of David Cummings Sprague, a hat-factory superintendent, and Frances Julia (King) Sprague. Born in 1857, he grew up and began grammar school in Milford, Connecticut, but after his mother died in 1866, he was sent to be cared for by an aunt in North Adams, Massachusetts. Here he completed his elementary education and then attended Drury High School, where he excelled in his science and mathematics courses. Seeking to further his scientific and technological training, he entered the competition for the limited number of slots at the United States Naval Academy. Although he won an appointment to the 1874 class, he needed to borrow $400 to pay for his travel to Annapolis, Maryland, and for his initial expenses.

During his four-year education at the Academy, he was always among the leading midshipmen in his classes, but especially in physics and chemistry. He passionately enjoyed laboratory work, even spending Saturday afternoons in experimental studies. His commanding officers later noted that it was through these courses that Sprague discovered his true vocation as an engineer and inventor. At the commencement ceremonies, attended by President Rutherford B. Hayes, Sprague graduated seventh in his class of thirty-six.

Life's Work

Commissioned as an ensign, Sprague experienced his first naval service aboard the USS *Richmond*, the flag-

THE FIRST COMMERCIAL ELECTRIC TRACTION SYSTEM

Just as there had been numerous incandescent lamps before Thomas Alva Edison, so too had there existed numerous experimental electric traction systems before Frank J. Sprague. During his naval career and his short time with Edison, Sprague had developed a versatile electric motor along with ideas of how to use it to power vehicles on tracks (so-called electric traction). When he formed his company and signed a contract with Richmond, Virginia, to install a twelve-mile electric railway, he had the chance to turn his dream into a reality.

Sprague approached the project as if it were a wartime task, and he in fact hired some former military engineers to help him. The contractor responsible for the track had been forced to include several steep grades and sharp curves along the route, which meant that Sprague had to redesign his electric motor to provide the variable power that would be needed. He mounted his motor so that it was geared directly to the axle, in a “wheelbarrow” arrangement that was widely adopted, since it helped to maintain motor-axle alignment no matter how irregular the car’s motion. By experimenting with many different ways of bringing electricity to the moving cars, Sprague and his team found a satisfactory swiveling trolley pole that maintained contact with the overhead electrical wire even around sharp curves. When the system began service, other problems arose—for example, the brass brushes bringing current to the rotating part of the motor created a metallic dust (a “golden road”) that contributed significantly to operational costs. This and additional problems were later solved by Sprague and others, but he was already beyond the time constraints of the project. He did lose $75,000 of his contracted fee, but the line was so successful that, during the next decades, cities using Sprague’s system proliferated all over the world. Soon horse- and mule-powered streetcars were things of the past.

ship of the Asiatic fleet, part of whose mission was to facilitate newly retired president Ulysses S. Grant’s triumphal world tour. From his letters and notebooks, historians learned that Sprague was keeping abreast of advances in the new electric lighting and telephone industries, and that he began designing, on paper, his own electric motors and telegraph systems. On his return to the United States, he used his leave to perform experiments at Stevens Institute, where he met William Wallace, an inventor who had developed dynamos for arc-lighting systems, and Moses G. Farmer, an inventor whose electric lighting system antedated Thomas Alva Edison’s.

In 1881, Sprague was assigned to the USS *Minnesota*, and when his ship docked in Rhode Island, he was able to visit Farmer, who was then official electrician at the U.S. Torpedo Station in Newport. Sprague was able to gain valuable experience working with Farmer on a new kind of dynamo, and this “inverted” type of dynamo became one of his first inventions. In 1882, when he was transferred to the USS *Lancaster*, the flagship of the European fleet, he was able, during the ship’s tour of the Mediterranean, to install an electric call-bell system, the first of its kind in the U.S. Navy. He obtained permission to visit electrical exhibitions in Paris and London. While traveling on London’s steam-powered underground railway, he began to think of the benefits of using electricity instead of steam. At the Crystal Palace site, he served as a secretary on a jury whose duty was to confer awards on the most innovative gas engines, dynamos, and incandescent lamps. Even though his leave was up, he remained in England to present a paper to the British Association for the Advancement of Science on Edison’s new method of delivering electricity. When he finally returned to his ship, he prepared a report on his experiences, which was later published by the Navy Department in Washington and probably saved him from a court-martial.

By this time, it had become clear to Sprague that his future was as an electrical engineer rather than a naval officer, and when, in 1883, Edward H. Johnson, an Edison associate he had met in London, urged him to resign from the Navy and work for Edison, he did just that. A few years earlier, Edison had built an experimental electric railway line at his facilities in Menlo Park, New Jersey, and Sprague thought he would be put to work on that project, but he became the electrical expert in Edison’s new Construction Department. He helped install the central station and overhead distribution system for electric lights in Sunbury, Pennsylvania. He also invented a formula for determining the optimum ratio of wire size to electric current, and he created an improved electric motor readily adaptable to various industrial machines. However, Sprague chafed as an Edison subordinate, and in his 1884 letter of resignation he stated that what Edison had done for the electric light he wanted to do for the electric railway.

Together with Johnson, Sprague founded the Sprague Electric Railway and Motor Company, which had an early success with Sprague’s constant-speed motor, which was mainly manufactured by the Edison Machine Works. Sprague now felt financially secure enough to marry Mary A. Keating in New Orleans, Louisiana. (The couple would have one son before eventually divorcing.) Sprague then spent time developing a generating (and regenerating) electric power system that he would later use to propel railway cars up steep grades and elevators in high buildings. He signed what he once called "a foolish contract" to furnish Richmond, Virginia, with an electric railway system in only ninety days, for which his company would receive $110,000. Because the route involved hills and curves, Sprague had to devise a motor that could efficiently respond to these demands and an electrical delivery system that involved an overhead trolley. Because of the time needed to solve these problems, Sprague missed the deadline and was penalized, but the Richmond trolley line proved to be so successful that, within two years, more than one hundred electric railroads that used Sprague's innovations were in existence in many U.S. and European cities and towns.

During his work on the Richmond system, Sprague purchased most of his company's equipment from the Edison General Electric Company, and in 1890 this company took over Sprague's. He was willing to let this happen because his attention had turned from horizontal transportation to a new venture, the vertical transportation of an electric elevator. In 1892, he founded the Sprague Electric Elevator Company to capitalize on the need for safe and swift transport in the increasingly taller buildings that were being built in American cities. With Charles R. Pratt, he designed an electric elevator that could travel faster and lift heavier loads than hydraulic and steam elevators. He proved the feasibility of his invention by constructing six elevators for the New York headquarters of the Postal Telegraph Company. After building hundreds of elevators for the tallest buildings in the world, Sprague sold his business to the Otis Elevator Company and focused his attention on developing a multiple-unit control system for electric trains.

In 1897, Sprague was able to convince Chicago officials that his new company could electrify the city's sole steam-powered elevated railway via a new system, in which each car had its own electric motor, though all were controllable by master switches in every car. This made possible long trains, with a concomitant gain in efficiency and revenue. Sprague oversaw the construction of the first multiple-unit system for the Chicago South Side Elevated Railway, and its great success led to similar installations in Manhattan, Brooklyn, and Boston. Buoyed by his new prosperity, he married Harriet Chapman Jones, a happy marriage that resulted in three children and lasted until his death. Repeating a pattern from his past, he sold his company to General Electric in 1902, and he then went on to found the Sprague Safety Control and Signal Corporation to make railway travel safer by designing automatic controls that necessitated compliance with trackside signals.

During Sprague's later career, he and his family lived in New York with a summer home in Connecticut, and his successes in fostering electric power led to his serving, in various roles, the electrical engineering profession as well as several cities, states, and the federal government. He continued to invent; for example, he created small electric power units suitable for machine tools, printing presses, dentists' drills, and home appliances. During World War I, he was a member of the Naval Consulting Board and helped develop the depth charges that were used against German U-boats. He received medals from the Franklin Institute and the American Institute of Electrical Engineers, an organization that he had served as president. In 1934, while he was terminally ill with pneumonia, he learned that he had been awarded the John Fritz Medal, and he was also able to examine a model of his latest invention. After his death in New York, he was buried in the National Cemetery in Arlington, Virginia.

IMPACT

Sprague was a pivotal figure in helping to transform the United States and much of the world from steam to electrical power. He was a leading innovator in a revolution in urban horizontal and vertical transportation. He was a member of a new breed of mathematically and scientifically trained engineers whose methods of discovery were more efficient than the trial-and-error techniques employed by such early inventors as Edison. In his lifetime, Sprague was often linked with Edison and Alexander Graham Bell as the "remarkable trio" of American inventors whose discoveries made possible modern electric-powered civilization. Unfortunately, since Sprague's death and the growth of what some have called the "Edison myth," the reputation of Edison has grown while that of Sprague has dwindled.

With the publication of Edison's private papers and notebooks, scholars now see that Edison had a propensity for claiming the innovations of his associates as his own. Sprague was particularly irked by Edison's assertion that he (Edison) had pioneered electric railways. Sprague had a nimble-witted mind, bubbling over with imaginative new ideas, and his assiduous energy propelled the best of his ideas into successful industries. His ideas facilitated the growth and prosperity of cities, and modern environmentalists note with sadness that his energy-efficient electric transportation system went into decline because of the aggressive marketing of less-efficient gasoline-powered automobiles, buses, and trucks. Although he never achieved the lasting fame of Edison, and although his inventions were not as many or as varied, his contributions to the expansion of electric-powered civilization rivaled, if not surpassed, those of his first employer.

—Robert J. Paradowski

Further Reading

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Hilton, George W., and John F. Due. *The Electric Interurban Railways in America*. Stanford, Calif.: Stanford University Press, 1960. The authors have collected much information on the rise and later decline of the electric railway. The book's first part deals with the general history, and the second with individual stories of important lines.

Melosi, Martin V. *Thomas A. Edison and the Modernization of America*. 2d ed. New York: Pearson Longman, 2008. In this new edition, the author emphasizes Edison's relationship with business and with such innovators as Nikola Tesla, George Westinghouse, and Frank Sprague. An updated sources section and an index.

Middleton, William D. *Metropolitan Railways: Rapid Transit in America*. Bloomington: Indiana University Press, 2003. This lavishly illustrated book surveys American transportation from the end of the eighteenth to the end of the twentieth century. Sprague's inventions and his first company are part of the story. Bibliography and index.

Sprague, Harriet. *Frank J. Sprague and the Edison Myth*. New York: William-Frederick Press, 1947. Sprague's second wife, who survived him by thirty-five years, tried to redress the imbalance between her husband's reputation and Edison's.

See also: Thomas Alva Edison; Elisha Graves Otis; Jesse W. Reno.

RANGASWAMY SRINIVASAN

Indian research scientist

Srinivasan pioneered ablative photodecomposition (APD) of organic materials using ultraviolet radiation. APD is extensively used in etching microcircuits and in laser-assisted in situ keratomileusis (LASIK), the surgical correction of myopia and astigmatism of the human eye.

Born: February 28, 1929; Madras, India
Primary fields: Chemistry; physics
Primary invention: Ablative photodecomposition

Early Life

Rangaswamy Srinivasan (RAHN-gah-swah-mee SHREE-nih-vah-sahn) was born in Madras, India, the youngest of four children born to Vedammal Rangaswamy and Rangaswamy Iyengar of the Iyengar community of southern India. He studied at the Pennathur Subramaniam (P.S.) High School in Mylapore, Madras, and Loyola College, Madras. He received a B.Sc. in chemistry (1949) and M.Sc. in physical chemistry (1950) from the University of Madras. Arriving in the United States in 1953, he received his Ph.D. in physical chemistry from the University of Southern California (USC) in 1956. He did postdoctoral research at USC (1956) and the University of Rochester, New York (1957-1961), before joining International Business Machines's research center in Yorktown Heights, New York. He won a Guggenheim Fellowship in 1965-1966. Srinivasan's early work on organic photochemical syntheses led to a book coauthored with Thomas Roberts in 1971.

Life's Work

Srinivasan's subsequent work focused on what he termed ablative photodecomposition (APD), a phenomenon of etching or drilling of organic solids such as plastics or tissue without any thermal damage to the surrounding substrate. The first lasers generated power in the infrared and later the visible part of the spectrum, but very little in the ultraviolet (UV). IBM reports in 1974 and 1975 discussed Srinivasan's team's photochemical studies on organic dye lasers to generate tunable UV power. In 1970, Nikolay Gennadiyevich Basov and colleagues at the Lebedev Institute of Physics in Moscow invented the pulsed excited-state complex (exciplex) excimer laser. In the late 1970's, high-power excimer lasers became available in the United States as spin-offs from CO_2 laser research by Northrop Corporation inventors (Manilal Bhaumik, U.S. Patent number 4,063,192, 1977). This opened opportunities for precise cutting applications in making microcircuits. Intense pulses of several different wavelengths in the far UV could be produced by using different gases.

2002 National Inventors
Hall of Fame
Induction Announcement

Rangaswamy Srinivasan was inducted into the National Inventors Hall of Fame in 2002 for his pioneering work in the field of LASIK eye surgery. (AP/Wide World Photos)

Dr. Srinivasan's discovery of ablative photodecomposition set off a flurry of research and led to the development of the LASIK eye surgery procedure. He authored more than 220 publications in refereed journals and a large number of conference papers and other presentations. A 1983 paper reported on depositing metal films on polymer surfaces photo-oxidized with UV radiation at 185 nanometers (nm). Several other papers in 1983-1985 discussed etching polymers using APD, indicating a drive toward better microcircuits. Publications on APD with organic tissue appeared in 1986, and on the dynamics of UV laser ablation of corneal tissue in 1987. Studies on laser pulses in the 100-femtosecond regime continued with different wavelengths and organic materials. A 1990 paper reported on using two simultaneous, coincident pulses of different wavelengths to ablate organic polymers. The emphasis then appeared to shift back toward longer (10-400 microseconds) pulses and then to continuous-wave (cw) radiation.

Srinivasan has twenty-two patents. U.S. Patent number 3,986,140, "2,4,6 Trisubstituted Pyridine Dye Lasers" (1976), by Channabasappa Angadiyavar and Srinivasan of IBM, describes an acidic dye solution and a pumping energy source combined into a dye laser operating between 410-nm (violet) and 570-nm (green) wavelengths. The maximum power of the output pulse is around 70 kilowatts. U.S. Patent number 4,414,059, "Far UV Patterning of Resist Materials" (1983), by Samuel E. Blum, Karen Brown, and Srinivasan, describes a technique to fabricate devices and circuits using multiple layers of materials, where material in the resist layer is selectively removed by APD. Energy at wavelengths below 220 nanometers is delivered in pulses exceeding 10 millijoules (mJ) per square centimeter, enough to fragment polymer chains and ablate the material, with no further processing required to make the desired pattern.

U.S. Patent number 4,417,948 (1983), issued to Veronica Mayne-Banton and Srinivasan, describes a self-developing technique for photoetching polyesters such as polyethylene teraphthalate (PET) by UV irradiation, removing material to at least 1,000 angstrom depth without degrading or heating the bulk of the PET material. This technique could be done in the presence of oxygen or air. U.S. Patent number 4,440,801 (1984), by Ari Aviram, Mayne-Banton, and Srinivasan, describes how to achieve electroless deposition of metals such as copper, silver, or gold onto a polymer substrate by preparing the areas to be deposited and then treating those areas with UV. Another patent (number 4,451,503, 1984), issued to Blum, Brown, and Srinivasan, shows how to deposit metals by UV photodecomposition of metal vapor rather than the substrate: A tungsten layer is deposited on a gallium arsenide substrate to form a Schottky diode. U.S. Patent number 4,568,632 (1986), by Blum, Karen L. Holloway, and Srinivasan, describes photoetching of polyimides with pulses of 60 mJ per square centimeter, with oxygen enhancing the etching rate. Another patent issued in 1986 extended the invention to a multilayer glass-metallized structure interconnected to multilayered metallized ceramic substrate. The UV laser was now used as a construction tool, drilling holes and forming the attachment points between layers.

Srinivasan's most important patent, shared with Blum and James E. Wynne, is "Far Ultraviolet Surgical and Dental Procedures" (number 4,784,135). Issued in 1988, the patent details the method and apparatus for removing organic biological matter using pulsed or cw radiation, specifically at 193 nanometers. U.S. Patent number 4,925,523 (1990) describes the use of a second pulse with a 308-nm xenon-chloride laser that follows the initial etching pulse with a 193-nm argon-fluoride laser, delayed by about twenty to thirty nanoseconds. This combination greatly improved the rate of etching while keeping the heating effects minimal. Typically, five hundred pulse pairs of this type were used for each etching. U.S. Patent number 5,246,885, issued to Bodil Braren, Brown, and Srinivasan in 1993, describes a method of superior fill of features in semiconductor processing using laser ablation.

Srinivasan has worked as a visiting research professor at the Edward S. Harkness Eye Institute of the Columbia-Presbyterian Medical Center (1984-1990); the Wellman Laser Lab, Harvard Medical School (1987-1989); and the City University of New York. Since 1990, he has headed UVTech Associates, a New York consulting firm. He is a fellow of the American Institute of Physics, the New York Academy of Sciences, the Association for the Advancement of Science, the American Physical Society, the Inter-American Photochemical Society, and the American Society for Laser Medicine and Surgery.

ABLATIVE PHOTODECOMPOSITION FOR LASIK

How does an engineer dig a neat trench just a few micrometers deep to lay microcircuits? The traditional approach was to etch the trench through a mask using a solvent such as an acid. This messy and expensive process involved many complex steps. In the 1970's, researchers at International Business Machines (IBM) were looking for a method for etching neat trenches. They found that lasers could be precisely focused to very high intensity but that infrared or visible lasers caused intense heating, destroying the material around the trench. Physical chemists such as Rangaswamy Srinivasan discovered ultraviolet (UV) wavelengths that would be absorbed directly into the chemical bonds of certain substances, causing them to ablate (vaporize and leave the surface) and losing little heat to the surrounding material. This was ablative photodecomposition (APD). The problem was finding a strong, precise UV source.

With the introduction of the excimer laser in the late 1970's, a solution was found. The nanosecond (ns) lifetimes of the excited-state molecules that released the laser energy produced intense nanosecond-long pulses compared to the microsecond pulses of dye lasers. (A nanosecond is one-thousandth of a microsecond.) It is helpful to note that a 1-millijoule (mJ) pulse delivered in 1 ns is equivalent to 1 megawatt, whereas the same pulse delivered in 1 microsecond is equivalent to only 1 kilowatt, which is one-thousandth of a megawatt.

In 1981, Srinivasan and IBM colleagues Samuel E. Blum and James E. Wynne conducted APD experiments on various materials. The ablated cells could be washed or would blow away at supersonic speed without damage to the surrounding substrate. Using a turkey bone from that year's Thanksgiving dinner, the researchers discovered that 193-nanometer (nm) UV pulses from an excimer laser would cut away the surface layer of organic tissue precisely and neatly, compared to incisions made with a continuous-wave green laser. Given the well-known heat sensitivity of human hair, electron micrographs of the IBM logo made by APD on a human hair powerfully demonstrated APD as a method for surgery as well as for micromachining of polymers and plastics.

The most famous surgical application of APD improves the keratomileusis procedure, in which thin flaps are cut from the cornea of the human eye to change lens curvature. Spanish opthalmologist Jose Barraquer had developed a thin knife called a microkeratome around 1950. Starting in 1983, opthalmologists in New York tested APD using lasers provided by the IBM group. The surgical reshaping of the cornea using APD won approval from the Food and Drug Administration (FDA) in 1995. Thus was born laser-assisted in situ keratomileusis (LASIK).

Blum, Srinivasan, and Wynne's 1988 patent, titled "Far Ultraviolet Surgical and Dental Procedures," describes the method and apparatus for removing organic biological matter using pulsed or continuous-wave radiation, specifically at 193 nanometers. The technique is "a method for removing selected areas of a biological layer comprised of organic material" by irradiating with several pulses of UV below 200 nanometers. The pulse intensity is about 10 mJ per square centimeter. Today, more than five million people worldwide have undergone LASIK surgery to improve their vision.

He was elected to the U.S. National Academy of Engineering (NAE) in 1999 and inducted into the National Inventors Hall of Fame in 2002. He has won numerous prizes and medals from professional societies. He has pursued his interest in history and archaeology to write a book on events in nineteenth century British-ruled southern India, where his grandfather served as a public prosecutor.

Impact

As Srinivasan's patents and papers demonstrate, the applications of ablative photodecomposition have multiplied over the years, ranging from microcircuit manufacture to dentistry to ophthalmology and other fields of surgery, down to the single-molecule level. Srinivasan's NAE citation reads: "For ultraviolet laser processing of polymers and its extension to refractive surgery of the cornea." LASIK surgery, which uses APD, has improved the eyesight of more than five million people worldwide.

—*Narayanan Komerath*

Further Reading

Srinivasan, R. "Ablation of Polymers and Biological Tissue by Ultraviolet Lasers." *Science* 234, no. 4776 (October 31, 1986): 559-565. Discusses how the APD process is conducted and gives an excellent perspective on APD as applied to biological tissue. Accessible to the lay science reader.

_______. "Twenty Years of Ablative Photodecomposition (Industrial Applications of Physics Prize Lecture)." *Proceedings of the American Physical Society*, March 22-26, 2004. Discusses the physics of ablative photodecomposition in simple terms. Mentions the motivations and steps along the way, as well as the remaining mysteries about the process.

Srinivasan, R., and B. Braren. "Ultraviolet Laser Ablation and Etching of Polymethyl Methacrylate Sensitized with an Organic Dopant." *Applied Physics* 45, no. 4 (Spring, 1988): 289-292. Discusses photoablation and etching of polymethyl methacrylate (PMMA) with 308- or 351-nm radiation by first doping PMMA with the organic compound Tinuvin. Gives chemistry details of the process.

Srinivasan, R., and T. D. Roberts, eds. *Organic Photochemical Syntheses*. New York: John Wiley & Sons, 1971. Useful and essential in both research and practical instruction, this book discusses the early, rigorous basic research that showed UV absorption by organic materials.

See also: George Biddell Airy; Theodore Harold Maiman.

Charles Proteus Steinmetz

German electrical engineer

Steinmetz made the everyday use of alternating electrical current practical by developing the mathematics necessary to calculate answers to practical problems. He was also instrumental in producing the techniques of transmission of electricity over long distances.

Born: April 6, 1865; Breslau, Prussia (now Wrocław, Poland)
Died: October 26, 1923; Schenectady, New York
Also known as: Karl August Rudolf Steinmetz (full name)
Primary field: Electronics and electrical engineering
Primary invention: Alternating-current calculations

Early Life

Named Karl August Rudolf Steinmetz at birth, Charles Proteus Steinmetz was born in 1865 in Prussia to German Protestant parents. His father, Carl Heinrich, worked for the railroad as a lithographer; he was later promoted to preparing train orders. His mother, Caroline Neubert Steinmetz, had two daughters by a previous marriage. Like both his father and grandfather, Steinmetz was afflicted with dwarfism, kyphosis ("hunchbackism"), and hip dysplasia. When he was only one year old, his mother died of cholera. His father then asked his own mother to live with his family. Steinmetz grew up in a home with his father and four women: his paternal grandmother, his father's sister, and his mother's two daughters by her first husband. As the youngest child and only boy in a house full of women, Steinmetz was spoiled by his family, especially his grandmother.

Steinmetz began his schooling at the age of five and a half. At first, he was a slow student, but he soon began to excel. He eventually graduated from high school with honors and entered the University of Breslau, where he

Charles Proteus Steinmetz. (Library of Congress)

studied for six years. In contrast to the behavior of many European university students of his era, he faithfully attended his classes and did all the suggested work. Although he completed all the work necessary for a doctoral degree, including a thesis, his studies did not prevent him from participating in social activities. He was particularly interested in the university students' socialist club. After the editor of the student socialist newspaper was jailed, he became its editor. However, this was a time when the Prussian government was building an empire and frowned upon socialism, and Steinmetz's political activities led to the government issuing a warrant for his arrest in 1888. Warned by friends that his arrest was imminent, Steinmetz fled to Austria and then to Zurich, Switzerland. He left Prussia without receiving his doctoral degree and without even being able to tell his family he was going. During half the year he remained in Zurich, he studied mechanical engineering at Zurich Polytechnic School.

Through his socialist friends, Steinmetz met a man named Oscar Asmussen, who invited him to return to the United States with him. Steinmetz had no money for the voyage, but Asmussen offered to pay his passage if they both traveled by steerage, the cheapest form of shipboard travel. When they arrived in the United States, Asmussen vouched for Steinmetz to immigration officials, who were reluctant to admit a dwarf who spoke little English into the United States. Within two weeks of his arrival, Steinmetz used a letter of introduction to American electrical engineer Rudolf Eickemeyer to obtain a job as a draftsman with Eickemeyer's company, Osterheld and Eickemeyer. In an effort to sound more American, Steinmetz changed his name from Karl to Charles and dropped August Rudolf. Noting that gentlemen generally had middle initials, he chose *P* for "Proteus," a nickname he had picked up during his university days. (Proteus was a Greek god who could take on any shape or form.)

LIFE'S WORK

Shortly after taking up his new position at the Osterheld and Eickemeyer company in Yonkers, New York, Steinmetz attended a lecture on alternating current in which a paper titled "Armature Reaction of Alternators" was presented. When he pointed out that the paper had failed to discuss the third harmonic, he was told that inclusion of the third harmonic would have made the presentation overly complicated. Steinmetz could not tolerate that omission, however, and worked out his own presentation—encompassing the third harmonic—which he presented three weeks later.

Any engineer designing an electrical apparatus using alternating current confronts the problem of hysteresis—the diminution of electrical power caused by changing magnetizing force. When electric current alternates, the north and south poles change places, but they do not do so instantaneously. The delay is called hysteresis. Steinmetz determined that hysteresis is proportional to the magnetism generated by the current. This causes a power loss that generates heat. In fact, a poorly designed apparatus can become red-hot. Steinmetz presented his law of hysteresis in the journal *Electrical Engineer* on December 8, 1891. His theory was immediately recognized as an important contribution to understanding electricity and remains an important part of electrical engineering to the present day.

The subject of Steinmetz's greatest success, alternating current, was less expensive to use and safer than direct current (such as that used by batteries), but no one knew how to calculate values for alternating current circuits. By this time, Eickemeyer's company had been bought by the new conglomerate known as General Electric, which wanted not only the patents Eickemeyer's company owned but also Steinmetz himself. So greatly did Steinmetz respect Eickemeyer that when the latter advised him to work for General Electric, Steinmetz went without hesitation. In Schenectady, New York, where General Electric eventually located him, Steinmetz conquered the problem of calculating alternating-current values. To do this, he devised a new way to express the problems in what he called a symbolic system.

Steinmetz believed that his three most important achievements were his mastery of electromagnetism, his invention of a practical way to calculate values for alternating current, and his research into lightning. His research on lightning would eventually be cut short by his comparatively early death, but he managed to develop a lightning arrester that senses lightning, opens a line to ground, and then stops electricity from following the lightning to the ground.

Steinmetz also invented devices to protect high-voltage power lines from lightning strikes, new types of electrical transmission cables, improvements to electrical transformers, and new methods of operating transmission systems. He designed an electric car and organized a company to produce it, but his company folded after his death. Before he died, he registered nearly two hundred patents and published several books, including works on alternating current, a history book, and a collection of lectures on relativity and space, in which he tried to explain Albert Einstein's theories to lay readers.

During his last ten years, Steinmetz taught at Schenectady's prestigious Union College without pay while working at General Electric part time. He became dean of the college's engineering school, whose curriculum he revamped. He also helped to reform the public schools of Schenectady and gave every orphan in the town a gift every Christmas. Universally well liked, Steinmetz was a bit of a prankster. He enjoyed weekly poker games and smoked cigars almost constantly. Although he never married, he was an outgoing, social person and took a young engineer, J. L. Hayden, and his family into his own household. On October 26, 1923, shortly after a Pacific Coast trip with Hayden, and his family Steinmetz died of a heart attack in Schenectady at the age of fifty-eight.

ALTERNATING-CURRENT CALCULATIONS

Charles Proteus Steinmetz once noted that "absolutely all the success I have had has been due to my thorough study of mathematics." Possibly the most outstanding invention of Steinmetz's mathematical mind was his ability to visualize an entirely new way to describe alternating current (AC). To see AC as a single number—even a complex number—was a concept that no one else had grasped. To simplify AC calculations, Steinmetz devised a new method. Before his time, AC had been described with a time-dependent equation that required graphical methods to show values of current at particular moments. Recognizing that this was not a practical way to make calculations, Steinmetz developed a system of symbols to use in AC calculations.

Steinmetz's method of making AC calculations was important because it made it possible for electrical engineers to design electrical devices and systems, such as machinery and power lines, so that their performance would be predictable. Prior to Steinmetz's calculations, an electrical system would have to be built first, then tested for efficiency—a very expensive and time-consuming approach. Steinmetz's system made it possible for electrical engineers to understand and work with alternating current and proved critical in the building of electric infrastructure at the turn of the century.

In 1893, Steinmetz presented his new method to the International Electrical Congress; its proceedings were not published until four years later. In the interim, Steinmetz's work could be used only by those whom he taught himself. His complete system filled three volumes and was understood by only a few people at that time. Moreover, only scientists with outstanding mathematical abilities could follow what Steinmetz had done and understand his symbols. Steinmetz explained his system again in *Theory and Calculation of Alternating Current Phenomena*, a book he published in 1897 with the help of Ernst Julius Berg. Steinmetz also wrote a textbook for college students, *Theoretical Elements of Electrical Engineering* (1902), and one for high school students, *Engineering Mathematics* (1911).

As dry and technical as these texts seem today, Steinmetz was not simply a mathematical genius. He put his abilities to sound practical use. Ignoring and overcoming the social obstacles his dwarfism may initially have provoked, he was loved by many and legendary for his sense of humor. On one occasion in 1902, when General Electric hired him to fix a system that no other technician had been able to repair, he billed the company ten thousand dollars—an enormous sum in 1902—for placing a chalk mark at the point where the system was broken. Balking at this fee, General Electric's managers requested an itemization. Steinmetz responded with the following list: "Making the chalk mark, $1. Knowing where to place the chalk mark, $9,999."

IMPACT

All engineers who work with electricity owe Steinmetz a debt of thanks. Without his new methods of calculating values of alternating current, electrical power would have spread more slowly, and fewer applications for it would have been developed. Electrical motors, kitchen appliances, power tools, televisions, computers, and hundreds of other devices would not have evolved as they have.

Until Steinmetz developed the law of hysteresis, the amount of hysteresis and power loss could not be calculated for electrical apparatuses, which had to be designed, built, and tested to determine how they would work with alternating current. Devices that lost too much power and became too hot were discarded and new apparatuses were designed. Thanks to Steinmetz's mathematical equations, engineers could calculate and predict power losses and heat gains due to magnetism before the apparatuses were built. This foreknowledge enabled them to design apparatuses that generated less magnetism and thereby experienced less power loss.

Steinmetz became aware that many engineers did not have the mathematical background to understand the theories and calculations that he was publishing. His textbooks on mathematics, which start very simply and build to what the engineers need, are still copied today, as is his text on electrical engineering. He even provided the mathematical background needed by electrical engineers, starting at the high school level.

—*C. Alton Hassell*

FURTHER READING

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Eveleth, Edmund I. *Achievers: Memorable Moments and Anecdotes of American Pioneers*. Destin, Fla.: Aviation, 2000. A collection of fourteen sketches of pioneers in various fields, including a brief chapter on Steinmetz. Illustrated.

Hammond, John Winthrop. *Charles Proteus Steinmetz: A Biography*. 1924. Reprint. New York: Gardners Books, 2007. Facsimile reprint of a biography originally published the year after Steinmetz's death. Steinmetz himself read and approved some of its chapters. Includes a foreword by Steinmetz's close friend J. L. Hayden. Illustrated. Index.

Leonard, Jonathan Norton. *Loki: The Life of Charles Proteus Steinmetz*. Garden City, N.Y.: Doubleday, Doran, 1929. The author was helped by J. W. Hammond, J. L. Hayden, and Steinmetz's secretary, Cecile Rhein. Illustrated.

Steinmetz, Charles P. *America and the New Epoch*. New York: Harper & Brothers, 1916. Steinmetz's attempt to view history scientifically, this volume opens with a consideration of the French Revolution and attempts to make a case for scientific socialism as it traces British and American history up to Steinmetz's own time.

_______. *Lectures on Electrical Engineering*. Edited by Philip L. Alger. 3 vols. Mineola, N.Y.: Dover, 2003. Alger was a coauthor of some of Steinmetz's other books. Illustrated. Indexes.

Steinmetz, Charles P., with Ernst Julius Berg. *Theory and Calculation of Alternating Current Phenomena*. New York: Electrical World and Engineer, 1900. Steinmetz's core work on alternating current. Technical, it is designed for physicists and electrical engineers.

See also: Thomas Alva Edison; Michael Faraday; Peter Cooper Hewitt; Nikola Tesla; George Westinghouse.

Great Lives from History

Inventors
& Inventions

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& Inventions

Volume 4

George Stephenson - Vladimir Zworykin
Indexes

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GEORGE STEPHENSON

English mechanical engineer

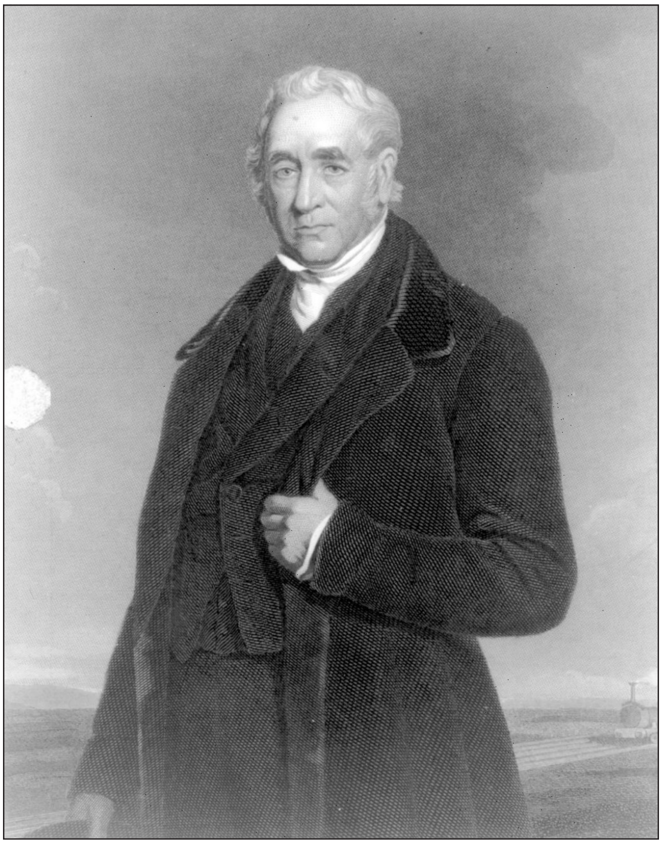
Stephenson built the world's first railway line to use steam locomotives. His Rocket *is considered the world's first successful steam locomotive, and his railroad track gauge became the world's standard gauge. Stephenson also invented the miner's safety lamp, used widely in northeastern England.*

Born: June 9, 1781; Wylam, Northumberland, England
Died: August 12, 1848; Chesterfield, Derbyshire, England
Primary field: Railway engineering
Primary inventions: Safety lamp; *Rocket* (steam locomotive)

EARLY LIFE

Born in the mining town of Wylam, England, George Stephenson spent his early life in poverty. By the age of ten, George was working in the mining pits sorting and breaking coal. His father, Robert, was a fireman for Wylam Colliery who supported his family on the meager salary of twelve shillings per week. Neither of his parents could read or write, and neither could George until he decided, at age seventeen, to attend night school. Also at this time, he became an engineman at a local mine. Three years later, he worked as a brakeman at Black Callerton Colliery, operating the winding gear of the mine. In 1802, he married and moved into one room of a cottage. A year later, his son, Robert (1803-1859), was born. To supplement his meager income, George mended shoes and fixed clocks. In 1804, he transferred to the Killingworth pit to obtain a slightly higher brakeman's salary. A daughter was born the following year but died three weeks after birth. In 1806, his wife, Fanny, died of consumption.

Life offered no opportunities for Stephenson until 1811, when the steam-driven pumping station at the Killingworth mine broke down and he volunteered to fix it. Success in this venture led to an engineering position with responsibilities for maintaining and repairing steam-driven machinery in neighboring mines. Two years later, Stephenson learned that efforts were being made in his native Wylam to design a steam-driven engine to run on tracks and haul coal out of the mine. Joining forces with John Thorswall, a skilled coal mine blacksmith, and Lord Ravensworth, the main owner of the Killingworth mine, Stephenson designed the *Blücher*, an engine that could pull on an upward incline eight cars loaded with thirty tons of coal at four miles per hour. Its major innovation was using flanged wheels to achieve adhesion and traction on iron rails. Although the engine was a success, Stephenson improved the *Blücher*'s power by introducing a blast of steam that increased the draft. He also began work to strengthen the iron rails needed to handle the tremendous weight produced by the coal. Joining forces with William Losh, who owned an ironworks in Newcastle, Stephenson patented an economical method for making cast-iron rails. Also in 1818, he helped alleviate one of the causes of mine explosions by developing the miner's safety lamp—though the discovery resulted in a fifteen-year patent dispute with the scientist Sir Humphry Davy. Ultimately, Parliament judged the discovery to be jointly shared and independently arrived at by both men.



George Stephenson. (Smithsonian Institution)

THE GREAT RACE AT RAINHILL

On October 6, 1829, a large crowd journeyed to Rainhill, England, to witness a competition among railroad engines. The crowd was drawn by what promised to be a revolutionary new technology for transportation of freight and passengers. Only four engines were entered in the competition. Many others under construction could not be entered because they were not completed in time. One was disqualified because it consisted only of a horse in a metal frame. The race was to take place on two miles of track. Each entry needed to make twenty trips during a single day at a speed of not less than ten miles per hour.

The first day consisted of trial runs. George and Robert Stephenson's *Rocket* completed twelve miles in fifty-three minutes. The second engine, the *Novelty*, made a far shorter trip but was able to reach a maximum speed of twenty-four miles per hour. The third engine, *Sans Pareil*, made an even shorter but successful trip. The fourth engine, *Perseverance*, was not ready for a trial run. The following day, when the race was supposed to begin, both the *Novelty* and *Sans Pareil* had to be repaired because of damage done in the trial run, and the *Perseverance* was still not ready. To entertain the spectators, George Stephenson brought out the *Rocket*, attached a thirty-passenger coach to it, and ran it on the track at a speed of between twenty-four and thirty miles per hour.

The great race finally began on October 8. Hauling about thirteen tons, the *Rocket* easily completed the twenty-mile course, reaching a top speed of twenty-nine miles per hour and an average speed of fifteen miles per hour, which was five miles over the minimum. All of the other competitors' engines broke down. The *Perseverance* finally got started but was able to achieve a speed of only five miles per hour before breaking down. Stephenson had won not only the prize but also the contract for building engines for the Liverpool-Manchester Line.

As for the *Rocket*, after service on the Liverpool and Manchester Railway it was used on Lord Carlisle's Railway in London. In 1862, it was donated to the Patent Office Museum in London, but in very modified form. It is housed today in the Science Museum in London. A replica of the *Rocket* was built to celebrate the 150th anniversary of the Rainhill trials. It is housed in the National Railway exhibit in York.

LIFE'S WORK

In 1821, Parliament permitted a twenty-five-mile line of track to be built to connect a number of mines between Darlington and Stockton. Since Edward Pease, the company director for the newly planned Stockton and Darlington Railway, was a partner in Stephenson's locomotive manufacturing company at Newcastle, Stephenson was contracted to build both the line and the locomotives. The line was completed in late September, 1825. Its wrought-iron tracks set at a 4-foot, 8.5-inch gauge became the worldwide standard. It was the first line to carry passengers (at the speed of fifteen miles per hour). Because of power issues with inclines, heavy freight could be hauled at an average of only five miles per hour. Still, the line was a success, and when plans were made to build a forty-mile line of track between Liverpool and Manchester, Stephenson was awarded the contract. In 1829, as the line was nearing completion, the Liverpool and Manchester Railway offered a prize of 550 pounds sterling for a locomotive weighing less than six tons that could pull a load of twenty tons at a minimum speed of ten miles per hour. The completion date was set for October 1, 1829.

For Stephenson, this was a challenge that could not be ignored. He worked with his son, Robert, trained in engineering work and educated at Edinburgh University, to build a steam locomotive called *Rocket*. Instead of a boiler with one large tube surrounded by water, the *Rocket* had twenty-five small copper tubes to significantly increase the heating surface. The system produced large volumes of steam while rapidly expelling exhaust gases. The *Rocket* also used a blast pipe that produced a partial vacuum that pulled large amounts of air into the boiler fire. The *Rocket* had two cylinders, set at 35-degree angles, driving the wheels. (Most previous engines had vertical cylinders.) The end result was an engine with a multitubular boiler that had far more power and less sway than anything produced before. When tested on the Killingworth Railway, the *Rocket* worked flawlessly. The engine was sent by wagon to Carlisle and then shipped to Liverpool to take part in the competition to be held at Rainhill.

Of the four engines entered at the Rainhill Trials, only Stephenson's *Rocket* was able to complete all requirements of the competition. While most thought the *Rocket* ran flawlessly, Stephenson knew that modifications needed to be made. The two cylinders were lowered eight degrees to provide a smoother ride, and the smokestack was immediately enlarged. The *Rocket* was sold to the Liverpool-Manchester Line, and four more engines were ordered from Stephenson. The opening of the world's first passenger line on September 15, 1830, was a major national event attended by the prime minister.

Having achieved national recognition, Stephenson became chief engineer for a wide variety of other railway construction projects, including lines from Derby to Leeds, Normanton to York, Birmingham to Derby, and Sheffield to Rotherham. Realizing that these lines would someday link up, Stephenson used the same railway gauge as his other lines. When the Institution of Mechanical Engineers was founded in 1847, he was elected its first president. A year later, the sixty-seven-year-old Stephenson contracted pleurisy. He died on August 12, 1848, and was buried at Holy Trinity Church in Chesterfield. Railroad construction, especially the building of tubular bridges of unprecedented size, was continued by his son, Robert, until the latter's death in 1859.

IMPACT

Stephenson was a pioneer of railroad engineering, helping to produce a transportation revolution in England that spread over the rest of Europe and worldwide. He was a creative force who helped make England the center of the First Industrial Revolution.

Stephenson did not build the first steam locomotive to run on tracks. This was accomplished on an experimental level by another Englishman, Richard Trevithick (1771-1833), twenty-five years earlier. What Stephenson accomplished was the design of an engine that made railroad transportation practical. The basic design of his *Rocket*—with its multitubular boiler to maximize heat transfer, blast pipe to draw air through the firebox, and direct coupling of pistons to driver wheels by connecting rods to maximize power transfer—was used in most steam locomotives up to modern times. Moreover, the laying of track throughout England at a gauge of 4 feet, 8.5 inches helped produce a national train network in Europe and became the worldwide standard gauge. It is often termed Stephenson's gauge.

Stephenson's rise from poverty to wealth and national recognition was used as a model for the work ethic of Victorian England. He became a figure of importance to Samuel Smiles, one of the most influential "self-help" writers of his day. The fact that Stephenson's national significance continues to modern times is symbolized by his portrait on the Bank of England's five-pound notes between 1990 and 2003.

—*Irwin Halfond*

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See also: Sir Humphry Davy; John Ericsson; Richard Trevithick.

JOHN STEVENS

American engineer

A pioneer of steamboat design and of the American railroad, Stevens invented the first steamship that sailed on the ocean and the first working American steam locomotive. Because of his advocacy of railroads over canals, he is called the "father of American railroads."

Born: 1749; New York, New York
Died: March 6, 1838; Hoboken, New Jersey
Also known as: John Stevens III (full name)
Primary fields: Mechanical engineering; naval engineering
Primary inventions: Steam-powered locomotive; steamship

EARLY LIFE

John Stevens was born in New York City in 1749. He was the son of the Honorable John Stevens, a wealthy landowner, shipowner, and merchant, who served as a New Jersey delegate to the Continental Congress, and Elizabeth Alexander, daughter of James Alexander, surveyor general of New York and New Jersey. The Stevens family had homes in both Perth Amboy, New Jersey, where the young John Stevens was raised, and in New York City. Stevens was educated largely by tutors, and later attended Kings College (later renamed Columbia University) in New York. Stevens graduated from Kings with a B.A. in 1768 and prepared for a career as a lawyer. He was admitted to the bar in 1771. Instead of practicing law, Stevens went to work with his father.

During the American Revolution, Stevens was granted a commission in the Continental Army, and it was in this period that he began his interest in inventing. In 1776, Stevens became treasurer of New Jersey, eventually rising to the rank of colonel, and for the rest of his life he was popularly known as Colonel Stevens. On October 17, 1782, he married Rachel Cox, daughter of Colonel John R. Cox, the deputy quartermaster general to General George Washington. After the revolution, Stevens and his wife moved first to the Stevens family home in New York City, and then on March 16, 1784, he bought a 689-acre piece of land that had been confiscated from a British Loyalist across from New York City, in what is now Hoboken, New Jersey. The Stevenses built a villa in Hoboken that was completed in 1787. They eventually had eleven children. In 1787, Stevens supported the ratification of the U.S. Constitution, writing a number of articles to this purpose, and in a pamphlet (signed "A Farmer of New Jersey") he even critiqued some of John Adams's constitutional ideas. Beginning in 1788, Stevens focused his creative mind on the subject that would captivate him for the rest of his life—steam power.

LIFE'S WORK

Stevens's attention was first drawn to the subject of steam power when, in the latter part of 1787, he viewed one of America's earliest steam ships operating on the Delaware River. He followed the ship to its berth and then studied its design. This was a ship built by John Fitch, with whom Stevens would soon be in competition.

Stevens turned his imagination to the problem of steam engine design after reading a series of pamphlets that appeared in 1788. The pamphlets were written by two American inventors who both claimed to have invented the steamboat. The first was James Rumsey, an inventor from Bath, Virginia, who began work on a steam-powered ship in 1785. Rumsey's first trial run in April, 1786, was disappointing. In December, 1787, he made his first successful trial run on the Potomac River. The other inventor was John Fitch, who also began his work on a steam-powered ship in 1785, and in August of 1787 Fitch successfully ran his steamship on the Delaware River. After reading these publications, with their conflicting claims of precedence for the creation of the steamboat, Stevens wrote to Rumsey with suggestions to improve the design of his engine and to increase its speed.

As a man of business, Stevens needed to commute between New York and New Jersey, and he appreciated the potential commercial benefits of this new steam technology. Such innovations could greatly increase the speed of commerce and industry. Stevens believed he could improve upon the designs of Rumsey and Fitch. With some innovative ideas of his own, Stevens decided to go into the steamship business himself. Stevens, along with Rumsey and Fitch, and a few others seeking federal protection of their steamboat designs, were granted federal patents under the new U.S. patent law on August 26, 1791.

Stevens's first partners were his brother-in-law, Robert R. Livingston (chancellor of New York State and later negotiator of the Louisiana Purchase), and Nicholas I. Roosevelt (inventor and ancestor of Presidents Theodore and Franklin D. Roosevelt). Livingston provided political influence and financial backing, and Roosevelt provided assistance in the building and design areas. Eventually, both Livingston and Roosevelt teamed up with Robert Fulton, a later competitor of Stevens. Stevens's sons eventually joined their father in the family business.

Beginning in 1798, Stevens made trial runs of various engine and propulsion designs. Among the design innovations that he and his colleagues tested were low- and high-pressure steam engines and single- and twin-screw propellers. In 1804, Stevens launched the *Little Juliana*, with a high-pressure tube boiler and a twin-screw propeller. In 1809, he ran the first steamship to sail on the ocean, the *Phoenix*, at a speed of 5.5 miles per hour. In this same year, he began steamship service between Philadelphia and Trenton, New Jersey. In 1811, he launched the *Juliana*, which was the world's first steam ferryboat, sailing between Hoboken and New York City. In 1812, he launched the *Philadelphia*, a 136.5-foot-long steamship with a speed of twelve miles per hour.

With an eye to facilitating the speed of business and travel on land as well as on water, in 1802 Stevens planned and later became the president of the Bergen Turnpike Company. He even proposed building bridges and tunnels connecting New Jersey with New York. In 1812, Stevens authored a very important document that has been called the "birth certificate of American railroads." His piece, titled "Documents Tending to Prove the Superior Advantages of Railways and Steam Carriages over Canal Navigation," applied the idea of steam technology to the railroad.

The Steam Waggon

In 1825, John Stevens built the first working steam-powered locomotive in the United States. Neither the original "steam waggon" nor any detailed plans exist. Nonetheless, the original boiler is in the Smithsonian Institution, and contemporary descriptions of Stevens's steam waggon do exist. The locomotive used an upright boiler similar to one Stevens had patented in 1803 for use on his steamboats. The steam waggon is thought to have operated with a boiler pressure of no more than fifty pounds. At just over sixteen feet long, the steam waggon had four wheels (with a diameter of around fifty-seven inches) that supported a flatbed wagon. The steam waggon was 6.25 feet wide, and from the top of the boiler to the bottom of the wheels, the locomotive was just under ten feet high. There were wooden benches for seats in the rear of the locomotive. It weighed 5,125 pounds and used a five-by-twelve-inch cylinder. To propel the railroad, Stevens used several gear wheels mounted in the middle of the wagon, the lowest of which fitted into a rack rail beneath the engine and which ran between and parallel to the tracks. The wheels themselves ran on a circular track, 660 feet in circumference, on Stevens's estate in Hoboken, New Jersey.

Stevens demonstrated his steam waggon for visitors who traveled from New York on his ferryboats. The steam waggon is said to have traveled at a speed of up to twelve miles per hour, even with passengers. While Stevens did not run his steam engine in Hoboken for financial gain, the visual demonstration of the first working American steam railroad proved to be a major step in the building of the American railroad. Stevens's steam waggon did not win over financial backers for his projected railroad projects, but within five years, the Stevens family would secure the charter for the Camden and Amboy Railroad in New Jersey. In 1831, Stevens's son Robert brought the *Stevens* (later the *John Bull*) from England as the first steam locomotive to run on the Camden and Amboy line. Within two years, the Camden and Amboy Railroad had fifteen additional steam locomotives running on their rail line, all built in New Jersey. Stevens's steam waggon was the first of its kind in the United States, and it helped give birth to a whole industry.

Stevens was a vocal proponent of railroads. In later years, he was recognized as a man ahead of his time in his advocacy of the benefits of rail transportation. Stevens proposed building railroads throughout the burgeoning United States, and in 1815 he obtained the first railroad charter in the country. This railroad was not built, but in 1825 Stevens built the first steam-powered locomotive in the United States, running up to twelve miles per hour. The locomotive, which Stevens called a "steam waggon," ran on a circular track on his estate in Hoboken. A replica of this engine is now on display at the Railroad Museum of Pennsylvania in Strasburg, Pennsylvania.

Stevens was the first to suggest building a railroad between Philadelphia and Columbia, Pennsylvania. Eventually, a railroad was built between those cities, the Philadelphia and Columbia Railroad, which was taken over by the Pennsylvania Railroad in 1857. In 1830, Stevens and his sons obtained a charter for the first railroad in New Jersey, the Camden and Amboy Railroad, one of earliest railroads in the country. It successfully carried passengers and cargo throughout the state. Stevens's son Robert Livingston Stevens became its president.

Impact

Stevens has been recognized as an inventor ahead of his age. He saw the possibilities of bridges and tunnels spanning rivers many years before these things became a reality, and he saw the potential of steam power to unite the economic resources of the American republic. Even as he advocated for railroads, he continued working on steamboats. Stevens's ferryboat service between Hoboken and New York helped spur the development of Hoboken. Passengers were transported to his Elysian Fields parkland on his Hoboken estate, where on June 19, 1846, the first recorded baseball game was conducted. The ferryboat service continued to remain in family hands into the early twentieth century.

Stevens lived to see the vindication of his arguments for the "superior advantages" of the railroad. His advocacy of railroads over canals encouraged the development of railroads throughout the United States. By the time Stevens died in 1838, the Camden and Amboy Railroad was just one of a growing number of railroads that were successfully operating in the United States. Stevens's son Robert invented the modern metal T-rail, the "hook-headed" spike, and the cowcatcher. He also designed the boiler for the Camden and Amboy's first locomotive, named *Stevens* (later known as the *John Bull*), which came from the shop of English railroad builder Robert Stephenson.

Prior to Stevens's death, he had hoped that a portion of his property could be used for a school of science. When his son Edwin died in 1868, he left an endowment and a city block to open the Stevens Institute of Technology, opened in 1870. The institute remains to this day a testament to the impact of John Stevens on American technology and engineering.

—J. Francis Watson

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Turner, Archibald Douglas. *John Stevens, an American Record*. New York: Century, 1928. The most complete and detailed biography of Stevens, with a great deal of information on Stevens's life, family, inventions, and patents. Illustrations, bibliography, index.

See also: Oliver Evans; John Fitch; Robert Fulton; George Stephenson.

GEORGE STIBITZ

American mathematician

Widely considered the "father of the modern digital computer," Stibitz was a visionary in the world of electronics who foresaw a number of uses for the computer. In 1940, he demonstrated the first long-distance transfer of computer data.

Born: April 20, 1904; York, Pennsylvania
Died: January 31, 1995; Hanover, New Hampshire
Also known as: George Robert Stibitz (full name)
Primary fields: Computer science; electronics and electrical engineering; mathematics
Primary invention: Model K (computer)

EARLY LIFE

George Robert Stibitz was born in the industrial town of York, Pennsylvania. At a young age, he showed intellectual promise, and his parents looked for opportunities to give their son an advanced education. Stibitz gained entrance into Moraine Park, an experimental secondary school in Dayton, Ohio. After graduating in 1922, he attended Denison University in Granville, Ohio, where he received a bachelor of philosophy degree in 1926. The following year, he received his master's degree from Union College in Schenectady, New York. In 1930, he earned a doctorate in mathematical physics from Cornell

University in Ithaca, New York. After earning his Ph.D., Stibitz accepted a job as a mathematical consultant to Bell Telephone Laboratories, the leading telecommunications company of the day, and began designing electronic circuitry to improve the nation's telephone systems.

Stibitz spent most of his earlier years at Bell Labs doing fairly conventional work relating to the company's key industry. Bell required a great deal of scientific effort to keep its telephone network functioning and was constantly looking for innovative ways to make its systems more efficient and cost-effective. Stibitz quickly earned a reputation for innovative thinking and was rapidly promoted for his efforts. He helped to develop phone circuits that could communicate with other circuits more efficiently. There were limits, however, to what Stibitz could do. Bell Labs was wary of technology that might make its own product obsolete, so innovative projects and concepts had to conform to the company's expectations. Stibitz began to turn his attention toward company projects unrelated to the telephone. He sought ways to use electronics in new ways that would expand Bell Labs' business opportunities without threatening its dominance of the telephone industry.

LIFE'S WORK

Starting with his graduate work at Cornell, Stibitz was interested in the practical application of electronic impulses other than to transmit a telephone message. The problem was how to make electronic devices, which had no intrinsic intelligence, "talk" to each other via a common language. However, even if a common language existed, these machines had to make "decisions" as a result of two or more instructions. Essentially, Stibitz's problem was how to get a machine that had no previous experience or knowledge to reach an outcome. If Stibitz was going to "teach" machines to perform, he had to teach them how to "think." The answer came in the form of Boolean logic and its use of switches. Using constant commands, such as "if," "then," and "not," Boolean logic allows outcomes from abstract or unintelligent processes. From a mathematical viewpoint, Boolean algebra allows the production of outcomes from uncertain or incomplete data. The same process, Stibitz realized, could also be applied to multiple electrical impulses moving through electronic gates to produce a result. The gates served as the "language" that allowed the machine to "learn." Stibitz set out to prove his process before he revealed it to the scientific world.

Working with salvaged parts, Stibitz in 1937 began constructing his first calculating device in his home. Because he was designing something completely new, he had to make some parts himself. For instance, he cut metal strips from tin cans to make electrical connectors. Stibitz called his first calculating device the Model K (for the kitchen table on which he assembled the computer). Despite its crude origins, the device could perform basic addition correctly every time. Though it was not the first computer (geared computers could calculate numbers through mechanical processes), the Model K was the prototype of the digital computer: Its calculations were performed entirely by electrical impulses moving through Boolean gates.

Demonstrating his device to his colleagues and supervisors at Bell Labs, Stibitz found a receptive audience. Bell Labs saw the commercial applications for the computer and placed Stibitz in charge of a project to improve the Model K. In 1940, Stibitz's Complex Number Calcu-

THE BINARY ADDER CIRCUIT

The innovation that made George Stibitz's digital computer possible was the binary adder circuit, the "brain" that allowed the computer to perform complex mathematical functions. When Stibitz began his work on his computer, the only circuits available were simple two-way circuits, capable of sending two impulses (inputs) and receiving two responses (outputs). These circuits became known as half-adder circuits, and they were the circuitry on radios of the day.

A half-adder circuit can send elemental bursts of data and is therefore suitable only for basic mathematical functions: It can add or subtract but cannot perform the higher math functions of multiplication and division, which require the extrapolation of data beyond mere linear sums. To make his Model K computer, Stibitz had to create an improved circuit. He designed the full-adder circuit, which has three inputs—the two available on the half-adder circuit, plus a "carry" function for higher-magnitude computations. This third function allows circuits to do multiplication and division by adding a third abstract variable. Technicians had to run the multiplication and division tables through the circuit to "teach" the circuit the outcome, but the circuit could "remember" the information. The encoding of the circuit to multiply and divide is an early example of computer programming. While outwardly the two types of circuits looked the same, the addition of the carry function expanded the capabilities of the digital computer.

lator (CNC), later renamed the Bell Labs Model Relay Computer, was introduced to the other scientists and engineers at Bell Labs. It was the the first true digital computer. The CNC could add, subtract, multiply, and divide complex numbers instantaneously and correctly every time. A few months later, in September, 1940, Stibitz demonstrated the CNC at the American Mathematical Society's national conference at Dartmouth College in New Hampshire. Besides its computational ability, Stibitz showed that it was possible to operate the computer from remote control. Using a Teletype machine to send a mathematical problem to the CNC in New York (250 miles away), he received a computed answer a fraction of a second later. Stibitz had performed the first long-distance transfer of computer data. Although the full realization of the potential of this function was still decades away, Stibitz's transmission was, in essence, a primitive form of the Internet. Stibitz had relayed data from one location, the data was processed at a second location, and an outcome was returned to the original sender. Stibitz's message heralded the age of mass information transfer.

During World War II, Stibitz became a member of the National Defense Research Committee (NDRC). Responsible for identifying, funding, and promoting scientific achievements to aid the war effort, the NDRC supported Stibitz's effort to expand on his computational theories first demonstrated with the CNC. His efforts helped expand the use of digital computers in the war effort in such areas as gunnery calculation, intelligence gathering, and secure communications. After the war, Stibitz returned to Bell Labs to work further on his calculating devices, but he perceived more uses for computers than those promoted by Bell Labs. He left Bell Labs in 1945 to work as a private consultant, and by the 1950's he had designed a prototype portable computer, though it did not have the power of the larger computers.

Stibitz's career took the computer in different directions in 1964, when he joined the faculty of Dartmouth College. There he pioneered the science of biomedicine, demonstrating that computers could measure and diagnose biological functions, such as generating computer models of blood circulation, airflow in the lungs, and reaction of organs to treatment. Combining computers with medicine revolutionized medical care since the 1960's, as computers made computed tomography (CT), magnetic resonance imaging (MRI), and other forms of remote diagnosis possible.

Stibitz retired from Dartmouth in 1983 but did not stop looking for applications for the digital computer. In his later years, he began to view the computer as a means of personal expression. Using the increasingly powerful personal computers available in the 1980's and 1990's, he explored the potential of computers to generate art and electronic music. Stibitz believed that, instead of merely expressing the direct vision of the artist, a computer could decipher the vision of the artist and generate its own image based on general inputs. Stibitz continued to work on this new application for the computer until his death in 1995.

IMPACT

Stibitz introduced the world to the digital computer, but he also demonstrated its vast potential. His computer had an immediate impact on science, technology, and communications. Thanks to his pioneering work, the Internet became a possibility and computer technology became an increasingly significant part of daily life. Computers now pervade nearly every aspect of modern life, from business to entertainment to shopping for groceries. Just as Stibitz stepped beyond the basic electronic, mathematical, and scientific uses of computers to introduce the technology to the medical field, other innovators followed his lead in applying digital computers in new ways.

—*Steven J. Ramold*

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See also: John Vincent Atanasoff; Charles Babbage; Clifford Berry; Seymour Cray; John Presper Eckert; Gottfried Wilhelm Leibniz; John William Mauchly; Claude Elwood Shannon; Alan Mathison Turing; Konrad Zuse.

ROBERT STIRLING

Scottish clergyman

A Church of Scotland minister, Stirling invented the Stirling hot-air engine, which he and his brother, civil engineer James Stirling, refined throughout their lives. Although never widely adopted, the Stirling engine is based on remarkable thermodynamic principles that promise great efficiency and energy conservation.

Born: October 25, 1790; Methven, Perthshire, Scotland
Died: June 6, 1878; Galston, Ayrshire, England
Primary field: Mechanical engineering
Primary invention: Stirling engine

EARLY LIFE

Robert Stirling was born in 1790 at Cloag Farm in the parish of Methven, Perthshire, in central Scotland. His father, Patrick Stirling, was a farmer. His mother was Agnis Stirling. The couple had eight children. Robert's grandfather, Michael Stirling, had invented a threshing machine in 1758. Robert attended Edinburgh University from 1805 to 1808, studying a wide range of classical subjects. In November, 1809, he enrolled as a divinity student at Glasgow University. On November 15, 1814, he returned to Edinburgh to continue his divinity studies. The following year, he was licensed as a minister in the Presbyterian Established Church of Scotland. On September 19, 1816, he was ordained as a minister in second charge of the Laigh Kirk parish in the prosperous town of Kilmarnock.

On July 10, Stirling married Jane Rankin, daughter of the local wine merchant. Their first child, Patrick, was born on June 29, 1820. Patrick would become an inventor and engineer in his own right. Robert and Jane would go on to have four additional sons (three of whom became engineers, and one of whom became a minister) and two daughters.

LIFE'S WORK

Stirling came from a line of industrious farmers who diligently worked to improve their mechanical implements. Stirling apparently showed mechanical aptitude from youth and was carrying out practical experiments while studying for the ministry. On September 27, 1816, only eight days after his ordination, Stirling applied for his first patent, for a fuel-efficient air engine. This was the first version of what would become the famous Stirling hot-air engine. Stirling was motivated to develop it both to save fuel and to design a safe alternative to boiler engines, which were prone to explosions. It is also possible that he was inspired by the investigations into the transmission of heat by Edinburgh professor of mathematics John Leslie. (It is unclear how much Stirling knew of earlier proposals to obtain power from heated air such as the 1794 heated-air engine of Thomas Mead and the 1807 open-cycle engine of George Cayley.)

Stirling's engine represented an improved method of storing and exchanging heat. It essentially worked by the alternative expansion and contraction of enclosed air acting upon a piston. To emphasize its fuel efficiency, Stirling called the central component of his engine the "economiser," although it would soon take the name of a "regenerator." It was the economiser that stored and released heat as the air circulated. With the promising start of his engine design, Stirling was able to acquire laboratory facilities from Thomas Morton, an inventor and the town industrialist. It would be a very productive partnership. In his Morton workshop, Stirling built numerous optical and scientific instruments, including the object glass of telescopes, which he ingeniously constructed from the bottoms of tumbler glasses. In 1818, he constructed an engine based on his economiser design to pump water from a stone quarry. The engine worked well, generating about two horsepower, until the air vessel became overheated and was crushed by the pressure of the heated air. Morton and Stirling later founded a free school in Kilmarnock to educate orphans and neglected children.

In 1823, Stirling took up a post as minister of the Galston parish. Although Stirling was involved in a dispute over the power of the established Church of Scotland over the local presbytery, his work on improving his engine designs continued unabated. In 1824, Robert and his brother James, a mechanical engineer, tried to improve the efficiency of the economiser with the use of high-pressure air by using metal sheets to subdivide the air into multiple layers. They received a patent for this improved engine in 1827. Although the patent application listed four improvements to Robert's original design, the new hot-air engine was not a success. James built an engine at the local ironworks, but it failed to produce the more efficient use of heat that was expected.

In 1840, Robert Stirling received an honorary doctorate in divinity degree from the University of St. Andrews for his erudition in classical languages and devoted ministry. In that same year, the brothers received another patent, for a new version of their engine. The patent application again listed four improvements, including forming materials into rods, employing these rods for receiving and imparting heat, passing the air through extensive systems of surfaces, and applying cupped leathered collars around the piston rods. James Stirling built two new engines based on these improvements for the iron foundry he managed in Dundee. These engines operated on coal and proved more successful, one running continuously for a period of two years and nine months until an air vessel failed. The new engines were able to generate about forty-five horsepower. However, the cylinders were prone to burn out quickly, a problem the Stirling brothers never solved. Robert blamed the failure of the engines on the imperfections of the materials used in their construction, an unlikely explanation. He continued to express hope that his engine would become the mainstay in production of the new Bessemer iron.

James Thomson, the brother of Lord Kelvin, claimed that Robert Stirling did not fully understand the principles of his own engine. Nevertheless, the regenerative principles demonstrated in Stirling's engine were successfully used by the inventor John Ericsson in his 1833 patented caloric engine; by Julius Jeffreys in his patented 1836 medical respirator; by industrialist brothers William and Frederick Siemens in their 1856 patented regenerative steam engine, condenser, and furnaces; by Edward Cooper in his 1857 patented hot-blast furnaces; and by F. T. Botta and G. B. Normand in their 1855 and 1856 patented chimney regenerators for use in marine boilers. For the remainder of their lives, Robert and James Stirling took out no new patents on the hot-air engine and apparently worked on it only sporadically. In 1878, after fifty-five years as minister of the Galston parish and continual refining of his hot-air engine, Stirling died on June 6.

STIRLING'S HOT-AIR ENGINE

In simplest terms, Robert Stirling invented an engine that heats air to obtain power. The Stirling hot-air engine is a closed-cycle, external combustion engine. In other words, the working fuel is designed to stay within the engine. Although Stirling originally named the innovative design of his engine the "economiser" to emphasize its fuel economy, it soon came to be called a "regenerator" because it uses an internal heat exchanger to increase the engine's thermal efficiency. With this heat exchange, the engine can reuse heat that would otherwise be dissipated. Because it operates under low pressure, the hot-air engine does not cause steam burns and is unlikely to explode. Stirling hoped that his hot-air engine would be adopted by iron foundries, making the smelting process safer and cheaper. However, it never proved fully satisfactory for either iron or steel production.

Stirling's engine combines numerous parts in its operation. The heater burns fuel in an external combustion chamber. Almost any fuel source can be used. Because the fuel is burned continuously, the Stirling engine tends to operate smoothly. The heater is connected to a gas-filled cylinder. Two opposing pistons compress the gas as it is heated and push the gas through the engine's heat exchanger and cooler. The cycle is then started again as the gas enters the heater. The heat exchanger stores the thermal energy emitted as the gas is compressed. The energy is then recaptured by the system, as explained by Nicolas Léonard Sadi Carnot's thermodynamic theory.

As Robert and James Stirling had mixed results with the engine, it never achieved wide popularity. Steam engines, greatly improved by the 1850's, continued to power England's industrial revolution. Nevertheless Stirling engines continued to be manufactured until the 1920's. After a period of nonuse, industrial interest in the Stirling engine was revived around World War II. Companies such as Dutch NV Philips experimented with a Stirling engine to generate radio power, and Ford Motor Company sought to use the engine in a fuel-efficient automobile. The Stirling engine's theoretical promise of almost complete efficiency without pollution continues to intrigue engineers. Even now, it is being proposed for hybrid-electric drive automobiles. However, the use of the Stirling engine remains to this day quite limited, confined mostly to specialized engines, cryogenic refrigerators, heat pumps, and small generators.

IMPACT

Robert Stirling lived the life of a distinguished country parson, becoming learned in biblical languages, arranging for charitable enterprises, succoring townspeople during a cholera epidemic, and pastoring his Church of Scotland flocks in the parishes of Laigh Kirk and Galston. During this life of religious duty, he and his brother James were working ambitiously on perfecting the design of the hot-air engine that had come to Robert as a youth.

Robert Stirling's idea for a hot-air engine had to some extent a charitable origin. He wanted to design an engine less susceptible to dangerous accidental explosions than the steam engine. With his mechanical mind, he focused on a design that centered on the efficient exchange of heat. How much of this design flowed from his understanding of thermodynamics is not certain, but the Stirling engine would in fact take advantage of scientific principles that were explained by the scientist Nicolas Léonard Sadi Carnot, who introduced the theory of the thermodynamic cycle. On April 21, 1847, William Thomson, better known as Lord Kelvin, the famed scientist who helped develop the laws of thermodynamics, delivered his first address to the Glasgow Philosophical Society on the subject of "Stirling's Air Engine." Thomson would also use the Stirling engine for demonstration purposes in his lectures at Edinburgh University.

The Stirling engine has intrigued engineers ever since, because of its theoretical possibilities for enormous efficiency and suggestion of a perpetual motion machine. However, no working Stirling engine has yet to come close to achieving this ideal. Although its use in industry remains limited, there are numerous researchers and Stirling engine societies convinced that its fundamental principles will one day provide a great breakthrough in the ability to generate clean, safe, and self-perpetuating power. Ingenious uses of these principles have been made over the last century. An engineer from Tyneside, England, John Malone, followed the Stirling model to invent a heat engine that used liquid at the critical point. Engineers at the Los Alamos National Laboratory have been experimenting with a Stirling engine that is powered by sound waves, and engineers from the National Aeronautics and Space Administration (NASA) have studied the use of Stirling engines with solar energy. Thus far, however, the Stirling hot-air engine remains more promise than reality.

—*Howard Bromberg*

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See also: Sir Henry Bessemer; John Ericsson; Werner Siemens.

LEVI STRAUSS

German American garment manufacturer

Strauss is responsible for the creation and production of blue jeans, a type of pants that became a staple in American fashion and across the world.

Born: February 26, 1829; Buttenheim, Bavaria (now in Germany)
Died: September 26, 1902; San Francisco, California
Also known as: Löb Strauss (birth name)
Primary field: Manufacturing
Primary invention: Blue jeans

EARLY LIFE

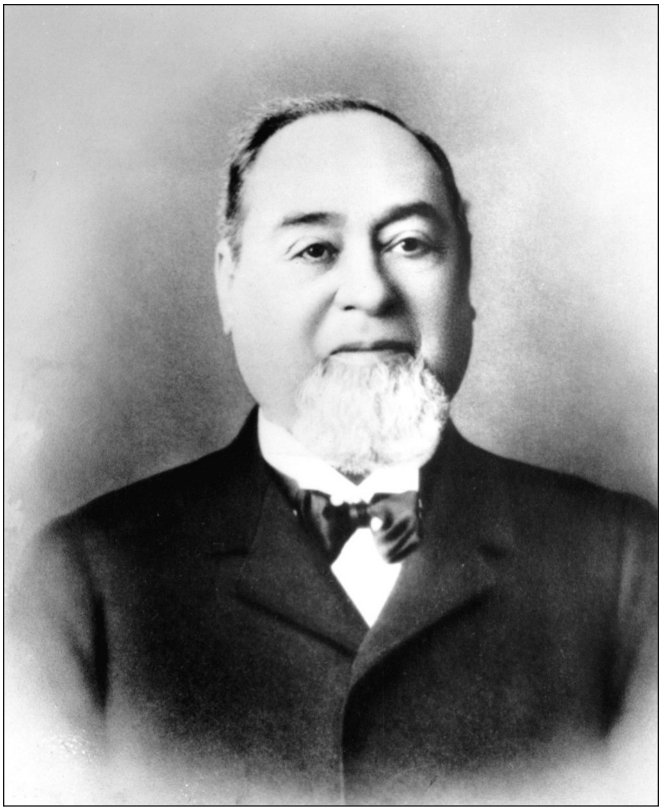
Levi Strauss was born Löb Strauss to German Jewish parents, Hirsch and Rebecca Strauss, in Buttenheim, Bavaria. He had four older siblings: Jonas, Louis, Fanny, and Mathilde. His father was a dry goods peddler who succumbed to tuberculosis in 1845. After his father's death, young Strauss traveled to the United States with Fanny, Mathilde, and their mother. They settled in New York, where they lived with Strauss's two older brothers, Jonas and Louis, who had previously arrived and set up a prosperous wholesale textile and tailoring business. Once in the United States, Strauss Americanized his name by changing it to Levi.

Strauss worked with his brothers during his brief stay in New York. He relocated to Louisville, Kentucky, where he lived on his uncle Daniel Goldman's ranch and learned the language. In Kentucky, Strauss worked as a door-to-door salesman peddling various goods, while dreaming of becoming an independent businessman. When the California gold rush hit in 1849, Strauss saw the opportunity to set up a business in the burgeoning region that would fulfill the needs of the miners and others who were flocking west to find their fortunes. In January, 1853, Strauss became an American citizen, and in February he traveled west to set up a dry goods business in San Francisco. He established Levi Strauss and Company with his sister Fanny's husband, David Stern. Strauss's business primarily sold materials that the mining community would need, such as scissors, buttons, thread, fabrics, and linens, but also carried household and specialty items imported from Europe and sent via ship from his brothers' business in New York.

Receiving goods via ship was often unpredictable and time-consuming. Although Strauss relied heavily on this method of shipment, he also purchased goods whenever they presented themselves at auctions at the docks, and from other salesmen traveling through the area. Strauss would often load his horse with supplies and travel into the mountain ranges where men would clamor to purchase his wares.

LIFE'S WORK

Strauss, along with Stern, had created a successful business and was well established in the community. Strauss worked closely with the miners, selling them needed supplies, and with other businesses that catered to the community. He sold fabric to local tailors and seamstresses who would turn the bolts into pants and outerwear for miners, who were very hard on their clothing. As his business began to prosper, Strauss also began buying real estate in Northern California, amassing a fair bit of wealth. A generous man, Strauss helped fund



Levi Strauss. (AP/Wide World Photos)

the construction of Temple Emanu-El, the first synagogue in San Francisco, and also belonged and donated to several organizations, including the Eureka Benevolent Society, the Pacific Hebrew Orphans Asylum and Home, and the Hebrew Board of Relief, which helped orphans, widows, and others in need. He also donated to several academic institutions.

By 1872, Strauss's reputation as a bright businessman and a philanthropist preceded him. That year, Strauss received a letter from Jacob Davis, a Reno, Nevada-based tailor who bought much of his fabric from Strauss. The poorly written letter explained that he frequently heard miners complain that their jeans were not able to withstand the rigorous work. The primary complaints were that the pockets would split apart at the seams when stuffed with ore and other materials. In the letter, Davis explained that he had developed a solution: reinforcing the corners of the seams around the pockets and at the tip of the fly with metal rivets. He wrote, "The secratt of them Pants is the Rivits that I put in those Pockots and I found the demand so large that I cannot make them up fast enough." The metal gave the jean pockets the extra strength necessary to withstand the rugged mining conditions. Davis wanted to file a patent for his design but did not have the capital. Knowing that Strauss was quite successful, and always looking for a good business opportunity, Davis offered to share the rights to the invention if he would fund the patent registration and legal fees. Strauss agreed, and the two men applied for their patent for an "Improvement in Fastening Pocket-Openings" in August of 1872. On May 20, 1873, they received their patent, and blue jeans were born.

Davis came to work for Strauss in 1873, overseeing the company's West Coast manufacturing operations. Stern died the following year at the age of fifty-one, and his four sons, Jacob, Luis, Sigmund, and Abraham, went to work for their uncle.

The jeans, then called "waist overalls," were an immediate success. They came in two styles—dark indigo blue denim and dark brown cotton duck. The denim products were much more popular, since the denim softened with washing, whereas the duck remained stiff. The duck was eventually dropped from the line altogether. In addition to making waist overalls, the company manufactured jackets and other durable outerwear articles, eventually producing solid-colored and patterned muslin button-up shirts.

Because of the overwhelming demand for the jeans, it quickly became clear to Strauss and his nephews that they would need to find a new distributor for denim. The company had been purchasing its denim from the Amoskeag Manufacturing Company in Manchester, New Hampshire, one of the oldest and most established textile mills in the country. In 1875, Strauss purchased the Mission and Pacific Woolen Mills to ensure that his company would always have a ready supply of material for its pants.

Although lack of railroad lines made national distribution of the jeans impossible, sales in the West were staggering. In 1886, the company introduced its trademark leather patch on the back waistband that depicted two horses attempting to pull apart a pair of the jeans. The original jean design was called XX but was changed to 501 in the 1890 catalog, the same year that the riveted pants patent expired. With the name and the logo in place, the jeans were positioned to become the cultural icon that they are today. Strauss incorporated his business in 1890, retaining a 55 percent share in the company and dividing the remainder between the seven Stern children. He had no children of his own.

Levi's Jeans

Levi Strauss was an American businessman who saw a good business opportunity, created a product to fill a need, and in doing so invented what became a quintessential American garment. The original Levi's 501 button-fly jeans were designed to be both durable and comfortable. Their material, denim, softened and conformed to the body with every wash, yet the resilient fabric did not fray. The seams were well constructed and strong. The secret to the success of the jeans was Strauss's patented metal rivets, which reinforced the pockets and button fly. The reinforcing rivets were created by a Nevada tailor, Jacob Davis, after he received frequent complaints from miners about their waist overalls (jeans) falling apart at the pockets and crotch. The extra support provided by the rivets allowed miners to use a single pair of jeans for years. The jeans' material and construction allowed them to withstand the rugged conditions of mining.

The innovation that Davis and Strauss employed in their product ensured their success, but the comfort and style of their jeans made the denim pants a fixture in the fashion world as well. Levi's jeans were worn by silver-screen icons such as John Wayne and James Dean, sparking demand for the jeans. Levi's jeans for women were first featured in *Vogue* magazine in 1935. Media attention further propelled Levi's jeans into the international spotlight.

Strauss began to suffer from a heart condition in his seventies. Although his company was in the able hands of his nephews, he continued to go into the office regularly to attend meetings and make decisions until his doctor insisted upon bed rest. Strauss died peacefully at his family estate on September 26, 1902, at the age of seventy-three.

IMPACT

The death of Strauss rocked the community, which felt that it had lost a civic leader and philanthropist. On the day of the funeral, many businesses were closed so that their owners could attend the services. The San Francisco Board of Trade passed a special resolution stating that "the great causes of education and charity have likewise suffered a signal loss in the death of Mr. Strauss, whose splendid endowments to the University of California will be an enduring testimonial of his worth as a liberal, public-minded citizen and whose numberless unostentatious acts of charity in which neither race nor creed were recognized, exemplified his broad and generous love for and sympathy with humanity."

Levi's 501 jeans became an American staple because of their unique and durable design and their comfort and easy care. Originally designed for miners, who needed rugged pants for their work, Levi's jeans have long been associated with cowboys and ranchers. With the explosion of cinema, however, the jeans took on a new role during the 1950's—the trademark of the rebel—as actors such as James Dean and Marlon Brando donned their blue jeans on the silver screen. The movie industry also helped to promote an association between Levi's jeans and youth and a carefree attitude. By the 1960's, Levi's jeans and other brands had become popular worldwide. Calvin Klein and other designers introduced their lines of "designer jeans" in the late 1970's, and these high-fashion jeans were popular through the 1980's. In 1986, Levi's introduced its Dockers line of casual pants, helping to establish the "business casual" style.

—*Sara Vidar*

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See also: Edmund Cartwright; Samuel Colt; Caresse Crosby; Isaac Merrit Singer; Sakichi Toyoda.

WILLIAM STURGEON

English electrical engineer

Sturgeon, a self-educated scientist, is credited with inventing the first electromagnet. He also invented the electric motor, a galvanometer, and a long-lasting battery cell. He was an energetic participator in the amateur scientific and learned societies of nineteenth century London.

Born: May 22, 1783; Whittington, Lancashire, England
Died: December 4, 1850; Prestwich, Lancashire, England
Primary fields: Electronics and electrical engineering; physics
Primary invention: Electromagnet

EARLY LIFE

William Sturgeon was born in Whittington, Lancashire, England, in 1783. His father, John Sturgeon, was a shoemaker of unsavory character and harsh with William. William's mother, Betsy Adcock Sturgeon, died when he was ten. At thirteen, William was apprenticed to a shoemaker, who was also known to treat the boy harshly. As a youth, Sturgeon, like many future inventors, showed mechanical skill, learning to clean clocks and watches. When his apprenticeship ended in 1802, he enlisted in the army, becoming an artilleryman. Sometime thereafter, he married Mary Hutton. Sadly, all three of their children died in infancy and Mary herself died in the 1820's.

Sturgeon told his friend John Leigh that his scientific interest in electricity was aroused while he was stationed in a military post in Newfoundland. Fascinated in watching a violent thunderstorm, he found no one who could explain to him the scientific causes of lightning. He therefore embarked on an impressive course of self-education. An artillery sergeant friend had a small collection of books, which Sturgeon borrowed, learning basic principles of Latin, mathematics, and science at night, after finishing his guard duty. He also studied optics and improved his mechanical skills. In 1820, Sturgeon retired from the military to reside in Woolwich, England. He supported himself with his former trade as a shoemaker, devoting his spare time to making his way in science. He also helped form the Woolwich Literary Society and began writing articles for the popular press.

LIFE'S WORK

With his unusual and self-taught learning, Sturgeon would always remain an outsider to the established British scientific community, despite his impressive accomplishments. Nevertheless, his scientific successes came quickly upon his 1820 return to England. With his tradesman background, Sturgeon began making his own instruments with a lathe he had purchased. Hans Christian Ørsted and André-Marie Ampère had recently discovered the fundamental principles of electromagnetism, and Sturgeon followed in their footsteps. He conducted experiments in magnetism and thermoelectricity and published his results in the scientific journal the *Philosophical Magazine*.

In the early 1820's, Sturgeon constructed a variety of apparatuses that demonstrated a range of electromagnetic effects. These dozen or so electromagnetic instruments were compact enough to be displayed on a tabletop. They were thus easily shown and demonstrated to an audience. One of the devices was a soft iron bar in the shape of a horseshoe. A coil of varnished copper wire was wrapped around the bar. When a voltaic current was passed through coil wire, the bar became magnetic. Sturgeon's iron bar is now considered the first working electromagnet, although Michael Faraday was never willing to credit Sturgeon for its invention. On the basis of this work, Sturgeon was awarded a silver medal and thirty guineas by the British Society of Arts. He was also appointed lecturer in experimental philosophy at the East India Company's Royal Military Academy at Addiscombe in Surrey. In addition, he gave paid lectures in other London scientific institutes, including the Adelaide Gallery, the Lowther Arcade at the Laboratory of Science, and the Western Literary and Scientific Institution.

ELECTROMAGNET

An electromagnet is a magnet that is generated by electricity. William Sturgeon built the first practical electromagnet in the 1820's. André-Marie Ampère had earlier proposed the idea of electrifying iron; François Arago had experimented with altering the magnetic properties of iron through rotation. Among the array of tabletop devices that Sturgeon built and exhibited in the early 1820's was the first workable electromagnet. It was generated by a single-cell battery. In a dramatic presentation on May 23, 1825, Sturgeon showed that his electromagnet, although weighing less than three-fourths of a pound, was capable of lifting a nine-pound object. The practical and industrial ramifications were obvious, and Sturgeon was awarded a valuable prize for his apparatus. Sturgeon's display demonstrated that solenoids—cylindrical coiled wires that produce a magnetic field when electrified—are strengthened when wrapped around an iron core. Sturgeon's electromagnet led to the invention of the telegraph in 1837 and the telephone in 1875. As a theoretical matter, it can even be said that Sturgeon's primitive electromagnet contributed to a line of inquiry that would eventually result in the great scientific achievement of James Clerk Maxwell's unified theory of electromagnetism.

Sturgeon's electromagnet consisted of a soft one-foot, seven-ounce iron bar in the shape of a horseshoe, around which Sturgeon wrapped eighteen turns of copper wire, the turns not touching each other. (The U shape of the electromagnet brings the poles together, concentrating the magnetic field.) When the wire was connected to a voltaic cell, the iron became magnetic and capable of lifting weights as heavy as nine pounds. Each wrapped coil reinforced the next, as they formed a set of parallel wires with the current moving in the same direction. The core of the iron was varnished so as to be insulated and not short-circuit the wires. When Sturgeon turned off the electric current, the iron's magnetic field disappeared. Sturgeon also demonstrated a straight bar electromagnet.

Within a few years, Joseph Henry was improving on Sturgeon's instrument, constructing electromagnets capable of lifting more than one thousand pounds. Electromagnets would become a vital generator of power in a wide range of uses. Their strength can be changed by altering the quantity of electric current, and is also dependent on the mass and structure of the iron core and copper wire. Electromagnets have been useful for many devices, including motors, bells, and various electronic instruments, and in industrial lifting.

He could now give up shoemaking for his scientific pursuits.

Sturgeon's success followed from his decision, as he explained it, to increase the magnetic, rather than the galvanic, power of his electromagnetic inventions. He designed his experiments such that they could be witnessed and understood by the emerging English middle class, who were transfixed by this amazing new force called electricity. A religious man, Sturgeon saw his new apparatuses as symbolic of the workings of the universe, actuated by the electriclike powers of the Creator. In 1826, he experimented with the firing of gunpowder by electrical discharges. In 1829, Sturgeon married Mary Bromley. In 1832, he invented an electric motor capable of turning machinery. The motor included a direct-current (DC) commutator. Over the next few years, Sturgeon invented the moving-coil galvanometer, improved the battery cell by amalgamating zinc plates with mercury, and discovered the unequal heating effects at the two poles of the voltaic arc. Making more than five hundred observations of experimental kites, Sturgeon published a meteorological study establishing that when weather is calm, the atmosphere is charged positively with respect to the earth, with the charge becoming more positive as the altitude increases. Joseph Henry, the American inventor and scientist of electricity, sought out Sturgeon on a trip to England to discuss their scientific work.

In 1836, Sturgeon launched a journal of experimental science, the *Annals of Electricity*, the first English journal devoted to electricity. Although the *Annals of Electricity* would publish important papers of Sturgeon and other inventors during its seven-year span, the contentious Sturgeon would also use its pages to critique rival scientists, particularly Faraday. Disdaining Great Britain's established Royal Society, chartered in 1662, and the Royal Institution, chartered in 1800, Sturgeon helped found a rival London Electrical Society in 1837. After a tenuous existence, the London Electrical Society disbanded in 1843 because of its accumulated debt. At the time, Sturgeon and Faraday had something of a rivalry. They both came from humble beginnings, but Faraday was well established as a fellow of the Royal Society. Faraday was, of course, the greater scientist and indeed was the leading experimenter of his day. Sturgeon's greatest talent lay perhaps not in theoretical work but in fashioning instruments demonstrating the latest scientific advances. In the invention of electromagnetic devices, he was hardly surpassed.

In 1840, Sturgeon became superintendent of the Royal Victoria Gallery of Practical Science in Manchester, leaving his London appointments. As superintendent, Sturgeon continued his lectures on electromagnetism. However, the gallery too had difficulty supporting itself, and it closed in 1842. Sturgeon started the Manchester Institute of Natural and Experimental Science in 1843, but it hardly got off the ground. Likewise, his new *Annals of Philosophical Discovery* folded after six issues.

For the rest of his life, Sturgeon supported himself as an itinerant lecturer with occasional bounties: two hundred pounds from the Royal Bounty Fund in 1847 and a fifty-pound annual pension from the British government in 1849. In his career, Sturgeon published sixty-nine papers cataloged by the Royal Society. He was able to collect and publish his major papers in an attractive volume titled *Scientific Researches*, funded by subscription. He was debilitated from a severe case of bronchitis in 1847. In 1850, he died at Prestwich, Manchester, possibly of influenza. He was survived by his wife, Mary.

IMPACT

Sturgeon is important to the world of invention and science on several fronts. He was a member of the remarkable group of scientists such as Ørsted, Ampère, and Faraday who discovered and advanced the basic principles of electromagnetism in the 1820's and 1830's. Although each of these scientists experimented with some form of charged magnet, Sturgeon's horseshoe-shaped "Improved Electro-Magnetic Apparatus" has a good claim to be the world's first workable electromagnet. Sturgeon's successful demonstration influenced Peter Barlow to attempt to apply the electromagnet to telegraphy and Joseph Henry to intensify the electromagnet, eventually leading to an electromagnetic telegraph as well as magnets capable of lifting three thousand pounds. In addition, Sturgeon invented the first electric motor capable of turning machinery.

Sturgeon was an active member in scientific societies, which helped to disseminate scientific ideas in early nineteenth century London and its surroundings. With scientific figures such as Barlow, Samuel Hunter Christie, Olinthus Gilbert Gregory, and James Marsh, London had an impressive number of learned men at the time, several of whom assisted Sturgeon with his career. An important element of Britain's industrial and scientific revolution, these societies also represent perhaps the first direct involvement of a prosperous middle class in the workings and publications of scientists. Sturgeon was tireless and hopeful in forming new societies and journals supported by popular subscription. Their existence was precarious and rarely survived a decade, but they did represent an alternative to the haughty royal societies, long the sole dispenser of scientific prestige and patronage in Britain. Sturgeon's efforts to publicize the details of his experiments were not only learned; they can now also be seen as an effort to democratize scientific effort.

With his mean upbringing and idiosyncratic education, Sturgeon stood outside the often aristocratic world of self-supporting, gentleman scientists. Sturgeon's journals reflect his grudge against Faraday, the most famous scientist of electromagnetism, and of the learned royal societies. Sturgeon appealed to his subscribers to validate his results, as opposed to Faraday, who presented his science as correct in itself and not dependent on wider acclaim. This is perhaps the reason Sturgeon was so eager to lay his instruments and the workings of his theories before a larger public. Sturgeon was not only making a rival claim about scientific discourse but also anticipating the competitive, journal-based and resource-driven nature of modern science.

—*Howard Bromberg*

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See also: Alexander Graham Bell; Michael Faraday; William Francis Giauque; Elisha Gray; Joseph Henry; Samuel F. B. Morse; Alessandro Volta.

THEODOR SVEDBERG

Swedish chemist

Svedberg made extensive contributions to physical chemistry, especially to the subfield of colloid chemistry. He invented the ultracentrifuge, a device for determining the sizes, densities, and distribution of very small particles. He also invented a balance for measuring low osmotic pressures.

Born: August 30, 1884; Fleräng, Valbo, Sweden
Died: February 25, 1971; Örebro, Sweden
Also known as: The Svedberg
Primary field: Chemistry
Primary invention: Ultracentrifuge

EARLY LIFE

Theodor Svedberg (TAY-oh-dahr SVEHD-bahryuh) was born in Fleräng, a small town in Sweden northeast of Stockholm, to Elias Svedberg and Augusta Alstermark Svedberg. His father, a civil engineer who managed different ironworks in Sweden and Norway, strongly influenced his only child by fostering an interest in science and an enduring love of nature. Theodor sometimes performed experiments in a laboratory at his father's workplace, and he regularly joined his father in long outings in the country.

Svedberg first attended the Köping School, then the

Karolinska School in Örebro as well as the Gothenburg Modern School. Two teachers let him use the school laboratories after classes. He built a radio transmitter and a Tesla transformer and gave public demonstrations at the school. He also prepared chemicals at home. Svedberg's love of nature drew him to botany, but he enjoyed physics and chemistry as well. He finally resolved to study chemistry, viewing it as a means to understand biological processes.

In 1904, Svedberg entered Uppsala University, where he received his bachelor's degree in 1905, after only a year and a half of study. His first publication, on a new method for creating organic compounds of metals in colloidal form, appeared the same year. He presented his doctoral dissertation in 1907 and accepted an appointment as lecturer in Uppsala's chemistry department.

LIFE'S WORK

As a student, Svedberg became interested in the new field of colloid chemistry. Colloids are mixtures containing particles intermediate in size between ordinary molecules and larger particles visible with a microscope. These substances include the materials necessary for life (such as starch, cellulose, and proteins) and countless natural and manufactured materials (foods, paints, gels, soaps, alloys, rubber, fog). Though invisible to the eye, colloidal particles can be viewed indirectly by reflected light with an ultramicroscope, a device for studying particles too small to be seen with an ordinary microscope. Svedberg built an ultramicroscope and published several papers on the production and motion of colloidal particles before completing his dissertation on colloidal solutions. He believed his observations verified theories of Albert Einstein and Marian Smoluchowski about the chaotic movements of small particles, known as Brownian motion. Svedberg's theoretical analyses were criticized by Einstein and Smoluchowski as well as by chemist Jean Perrin.

Theodor Svedberg. (©The Nobel Foundation)

Radioactivity was also a new and exciting field at this time. Svedberg decided to determine where new radioactive substances might fit in the periodic table. Working with his colleague Daniel Strömholm, he found that corresponding members of the three radioactive series were extremely similar chemically. In 1909, Strömholm and Svedberg proposed that the periodic table based on atomic weight was only an approximation. Rather than being completely uniform in weight, elements were mixtures of chemically identical substances having slightly different weights. This was the earliest formulation of the concept of isotopes, a conceptual breakthrough with profound theoretical and practical consequences.

In 1912, Svedberg became the first professor of physical chemistry at Uppsala, a position that the university instituted for him. Colloids remained his main interest. Contrary to expectations, his research showed that colloids lacked properties that sharply distinguished them from other types of matter. Such findings eventually erased the distinction between colloid and physical chemistry.

Svedberg needed to use a centrifuge to progress in his work. This apparatus would apply extra force to the particles he was studying and cause them to sediment more rapidly. Since research funds were scarce after World War I, he became discouraged.

A visiting position at the University of Wisconsin at Madison in 1923 was a godsend. Svedberg thrived in Madison's stimulating atmosphere. With J. B. Nichols, he built a centrifuge in which the sedimentation process could be recorded by photography. However, technical problems precluded useful measurements.

Rejuvenated by the Wisconsin experience, Svedberg returned to Sweden full of ideas and enthusiasm. In 1924, he and Hermann Rinde built the first working centrifuge for investigating colloids. They named this device the "ultracentrifuge," following the pattern used for the terms "ultramicroscope" and "ultrafiltration." Driven by an electric motor, this machine could rotate up to 8,700 times per minute and create a force up to 5,000 times the gravitational field.

Svedberg decided to use the ultracentrifuge to find the size distribution and molecular weights of proteins, which chemists believed were not uniform in size. To his surprise, tests with hemoglobin showed that all the particles were the same size. Just as amazing was the result that the molecular weight of hemoglobin was four times that predicted from its composition.

The first ultracentrifuge was unstable and unreliable, and it exhibited numerous problems. Explosions and breakage were common occurrences. Svedberg and his coworkers redesigned this device many times. Though it was suitable for many purposes, a different mechanism was needed to speed the centrifugation process and to enable researchers to distinguish components in a complex mixture.

In 1926, Svedberg and others constructed a high-speed ultracentrifuge powered by an oil-driven turbine instead of an electric motor. Early versions could rotate approximately 45,000 times per minute, producing a force approximately 100,000 times that of gravity. While working on this machine, Svedberg was awarded the 1926 Nobel Prize in Chemistry for his work on colloidal systems.

The award enhanced Svedberg's status. The Swedish legislature agreed to fund a physical chemistry laboratory, which was completed in 1931. Privately, Svedberg felt that the award was premature. The Nobel Committee had thought that his early incorrect theoretical work corroborated the existence of molecules. He resolved to prove himself worthy of the award and threw himself into a whirlwind of activity. He concentrated on improving the ultracentrifuge and using it to study proteins and other large molecules.

During World War II Svedberg worked on synthetic rubber production. With a coworker, he invented a bal-

THE ULTRACENTRIFUGE

A centrifuge is a rotating device that can be used to separate different materials. This machine creates a force along its axis of rotation that causes the denser particles to move outward, while the less dense particles collect near the center. The design, dimensions, and materials for a centrifuge depend on the kinds of substances to be separated.

Different types of particles in a suspension can sometimes be separated by allowing them to settle. Under the influence of gravity, denser particles will fall toward the bottom of a container, while the lighter particles will rise to the top. Settling does not work well with very small particles because the gravitational forces will be overwhelmed by other factors that affect the particles' behavior. In these cases, the increased force provided by a centrifuge is essential for separation and for measuring the speeds, concentration variations, and other properties of suspended particles.

Theodor Svedberg and Hermann Rinde built the first ultracentrifuge with parts from a machine used for separating cream from milk. An electric motor connected to a gear drive drove a brass shaft (the rotor) that rapidly rotated the samples, which were enclosed between glass plates in compartments, or cells. A prism reflected light into the centrifuge from a bright lamp to illuminate the materials so that their behaviors could be observed. Svedberg suspended a camera over the apparatus to record the progress of changes in a sample by photographing it through a window in the apparatus. Rubber plates and tubing were used to isolate the apparatus and to reduce vibrations. Oil lubricated the centrifuge's moving parts, while water and hydrogen cooled areas subject to friction.

Svedberg and others first constructed a centrifuge driven by an oil turbine in 1926. This machine reduced the operating time required and made it possible to analyze many more substances. During the late 1920's and the 1930's, other scientists developed a high-speed ultracentrifuge propelled by an air turbine.

The ultracentrifuge revolutionized the study of colloids by enabling chemists to determine particle sizes and molecular weights of particles too small to be seen directly in an optical microscope. The ultracentrifuge made it possible to study proteins and other macromolecules, leading to the development of molecular biology and modern biochemistry and biophysics, with applications in medicine and industry. The ultracentrifuge became a standard fixture in well-equipped laboratories, essential for determining molecular weights of large molecules and linear polymers and desirable for gleaning thermodynamic and hydrodynamic data. Now often coupled with computer software, this device provides a simple, nondestructive method for gaining quantitative information about complex systems.

ance for finding molecular weights of polymers by osmosis in 1944. He also investigated the actions of radiations on proteins and built a neutron generator for such tests and to prepare radioactive tracers.

Svedberg was interested in relationships between academia and industry, and he was instrumental in founding the Research Council for Technology. He obtained funding from an industrialist to build a large cyclotron for research and medical applications. This machine was ready in the new Gustaf Werner Institute in 1949, the year of Svedberg's mandatory retirement. Svedberg became head of the institute, where he continued research and collaborations with Swedish industries until his second retirement in 1967.

So closely was Svedberg associated with the ultracentrifuge and the researches this invention made possible that his peers named a measurement unit after him. The svedberg (S or Sv) equals 10^{-13} seconds. It is used to measure the sedimentation rate of a suspended particle moving at constant speed.

Svedberg received numerous awards and honorary degrees, and he was elected to more than thirty learned societies, including the Royal Society in London and the American National Academy of Sciences. He died in Örebro on February 25, 1971.

Impact

Svedberg was a brilliant, innovative, and indefatigable researcher whose research and inventions advanced several scientific areas and contributed to the birth of a new field, molecular biology. His work had far-reaching consequences for areas as diverse as chemistry, biology, medicine, metallurgy, manufacturing, nuclear science, agriculture, and food processing.

Svedberg's radiochemical investigations helped establish the existence of isotopes, which have had extensive applications in research, medicine, archaeology, technology, and industry. Radioactive isotopes are widely employed as tracers to mark nonradioactive elements, allowing researchers to follow physiological and industrial processes and chemical reactions.

Svedberg made his most significant contributions to the field of colloid chemistry. Directly and through his students, Svedberg established the existence of macromolecules, found the weight of many proteins and other substances, and determined that proteins were well defined in size. Svedberg's research and invention of the ultracentrifuge sparked an explosion of research on the large molecules that compose living things, facilitating the identification of viruses and the development of modern biochemistry. He contributed to conceptual change in chemistry by showing that colloids lacked unique properties and establishing the existence of macromolecules, which became the new disciplinary focus.

Svedberg transformed physical chemistry in Sweden by building up the University of Uppsala's chemical laboratories and mentoring numerous students. He created a fruitful exchange between academic and industrial research in Sweden by his individual efforts and through his work with the Research Council for Technology. Under Svedberg's leadership, the Gustaf Werner Institute advanced research on radiation, its effects on macromolecules, and its applications to medicine.

—*Marjorie C. Malley*

Further Reading

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See also: Dimitry Ivanovich Mendeleyev; Richard Zsigmondy.

JOSEPH WILSON SWAN

English physicist and chemist

Swan made several important contributions to the early development of photographic printing and was the first person to patent an electric incandescent lamp, whose manufacture and refinement led to further significant technological discoveries.

Born: October 31, 1828; Sunderland, County Durham, England
Died: May 27, 1914; Warlingham, Surrey, England
Also known as: Sir Joseph Wilson Swan
Primary fields: Chemistry; photography; physics
Primary inventions: Electric incandescent lamp; dry photographic plate

EARLY LIFE

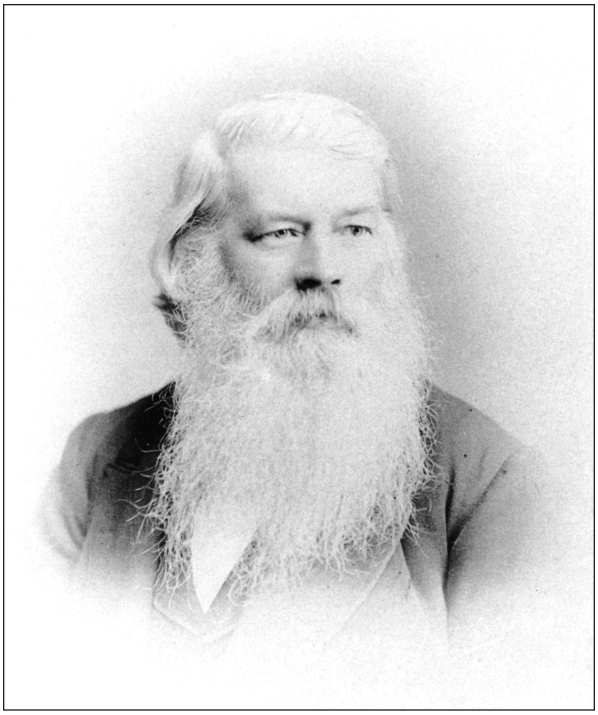
Joseph Wilson Swan was the third of eight children born to John Swan and his wife Isabella, née Cameron, who were both of Scottish descent. The family had been fairly prosperous in previous generations but had declined into an uncomfortable poverty. Joseph attended schools in Sunderland before being apprenticed at the age of thirteen to a firm of druggists in that town, Hudson and Osbaldiston. Both the partners died within three years, liberating Joseph from his obligation, and he went to join a family friend, John Mawson, in operating a druggist's shop in Newcastle upon Tyne. There he became a pillar of the local Literary and Philosophical Society.

Mawson subsequently married one of Swan's sisters before dying in an accident in 1867, leaving Swan as sole proprietor of their business. Swan subsequently took on another partner in order to concentrate his own efforts on research work. The druggist's shop continued to operate from the same premises in Grey Street when Swan eventually moved to London, and it functioned under the name Mawson, Swan, and Morgan until it finally closed its doors in 1973.

Swan married Frances White, the daughter of a Liverpool merchant, on July 31, 1862; three of their five children survived to adulthood (two twins perishing in infancy), but Frances died in 1868. Swan subsequently married her sister Hannah in 1871; that second marriage produced five children, all of whom survived to adulthood, although the youngest daughter predeceased her father, dying at twenty-nine. From 1869 until he moved south, Swan and his family were resident at Low Fell, near Gateshead.

LIFE'S WORK

While working with John Mawson, Swan became very interested in photography, and the shop's facilities provided him with a suitable environment for exploring its chemistry and technology. Their business expanded to market a number of products originated by Swan, including an improved collodion—a viscous solution of pyrox-



Joseph Wilson Swan. (Smithsonian Institution)

The Electric Incandescent Lamp

Two vital problems had to be solved before the phenomenon of electrically induced incandescence could be adapted to serve in a viable lamp: finding a filament that would produce an adequate amount of radiation over a long period of time without fracturing or burning out, and successfully maintaining that filament in a vacuum for a similar length of time. The crucial breakthrough came when Hermann Sprengel developed an improved vacuum pump, which facilitated the evacuation of glass bulbs that could be sealed without significant inward leakage; Joseph Wilson Swan was quick to realize this, as was Thomas Alva Edison in the United States.

The solutions to the former problem found by Edison and Swan were almost exactly the same, both involving carbonized filaments. The main difference was that Edison initially preferred a bamboo filament to Swan's weaker thread filament, but any superiority the Edison product temporarily enjoyed was lost when Swan developed the superior extruded cellulose filament, which Edison was slow to adopt. (Both filaments eventually became redundant when coiled tungsten filaments were developed.) The careful shaping of the containing glass bulb so as to secure its tensile strength, and the seal binding it to the housing of the electrical contacts, were also crucial to the success of the technology.

Electrical lighting was a far more efficient means of lighting streets and homes than gaslight or candlelight. It completed a revolution against the tyranny of night that made the streets infinitely safer, initiating the era of modern policing, and made reading so much easier as to institute revolutions in both popular fiction and education. The technology's abundant spin-offs included the entire realm of practical electronics.

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ylin in a mixture of organic solvents, including alcohol, ether, and acetone, used as a coating for photographic surfaces. "Mawson's collodion" became a famous local product in northeast England.

Swan went on to devise a refined version of the carbon process for producing permanent photographic prints, which he perfected in 1864. This technology, considerably more significant than the previous one, became the basis of photogravure printing, and he continued to work on the improvement of that application by producing and marketing half-tone blocks for use in printing. He began producing bromide dry plates in 1877, and Mawson and Swan's bromide plates (Swan maintained his brother-in-law's name on their produce although Mawson was long dead by then) also became celebrated as a commercial product. He followed up this discovery by adapting it in 1879 to the production of bromide paper.

In 1845, when he was only sixteen, Swan had been present at a demonstration of electrically induced incandescence at Sunderland Atheneum. The phenomenon was already well known, and the prospect of adapting it for use in lamps was clearly visible on the technological horizon, but the practicalities of developing such a lamp proved awkward. Swan began experimenting with electrical incandescence in 1860, twenty years before Thomas Alva Edison took up the problem in the United States. Swan actually took out a patent on an incandescent bulb, but his prototypes were unsatisfactory, partly because the vacuum within his bulbs could not be effectively sustained and partly because the incandescent material could not be refined to the point at which the lamps were sufficiently long-lived for commercial exploitation. Swan therefore set the problem aside to concentrate on his experiments with photography.

The existence of the Swan patent was something of an inconvenience to Edison when he set out to develop an electric lamp of his own in the late 1870's. Swan also resumed work on his electric lamp at about the same time. Both men had been encouraged to do so by Hermann Sprengel's invention in 1875 of a new vacuum pump, which opened up the possibility of producing efficiently evacuated sealed bulbs to contain incandescent filaments. Swan substituted carbonized thread for the bulkier slivers of wood that he had earlier used as filaments, while Edison applied for a new patent employing a bamboo filament.

Swan demonstrated his electric lamp privately for the first time in December, 1878, and then gave a public demonstration at a meeting of the Newcastle Literary and Philosophical Society in February, 1879. A further eighteen months of development produced a product that was technically and commercially viable, which was demonstrated at another meeting of the Literary and Philosophical Society on October 20, 1880. The room was entirely lit for the occasion by Swan lamps. Swan went on to demonstrate his lamp at the Institute of Electrical Engineers, and it was shown at a Paris Exhibition in the following year.

Swan's own house was the first to be lit by electricity, but a fellow member of the Newcastle Literary and Philosophical Society, Lord Armstrong, soon commissioned him to install electric lighting at his home, Cragside, near Rothbury. More domestic installations followed, but the lamp's first great publicity coup was at the Savoy Theatre in London, where the D'Oyly Carte company had a set installed as a component of its stage lighting, using the lamps for the first time to light the fairy scenes in W. S. Gilbert and Arthur Sullivan's *Iolanthe* (1882).

Swan set up a company to market his electric lamp before the end of 1880, but it was superseded by a larger company in 1882; it was at that point that the Edison Company initiated legal action for patent infringement. Given that an English court was highly likely to uphold Swan's original patent, the action might have been a nuisance suit intended to tie up Swan's finances. The case, however, never came to court, because the two companies agreed to combine their operations in England as the Edison and Swan United Electric Light Company, while Edison continued to enjoy a monopoly in the United States. By this time, Swan had further improved his design, using an extruded cellulose filament, and all the lamps sold in Great Britain thereafter were made to Swan's design, while Edison continued to use his own filaments in the United States for several more years.

Because the Edison and Swan United Electric Light Company took over the Edison Company's former local headquarters in London, Swan moved his family south from Low Fell, initially settling in Bromley, Kent, in 1883. The company moved to Ponders End in 1886, where it expanded considerably, eventually establishing a factory to make thermionic valves in 1916, thus becoming the foundation stone of the British electronics industry. Swan subsequently bought a house in Holland Park in 1894, the year in which he was elected as a fellow of the Royal Society. In 1898, he became president of the Institute of Electrical Engineers. In 1900, he received an honorary doctorate from the University of Durham, which had previously presented him with an honorary M.A. He subsequently served as president of the Faraday Society and—perhaps somewhat belatedly—as president of the Literary and Philosophical Society of Newcastle upon Tyne. He was knighted in 1904.

Although the electric lamp made his fortune, Swan did not rest on his laurels; he continued to seek innovations in various fields as he had throughout his career. His other major achievements included the chrome tanning process for leather and the cellular lead plate for use in rechargeable batteries, for which he had obtained a patent in 1881. The method by which he eventually produced extruded cellulose filaments for use in electric lamps also proved adaptable to other purposes, the most notable being the manufacture of artificial silk, another of his discoveries. His activity was eventually curtailed by health problems, and in 1908 he moved to Overhill, near Warlingham in Surrey, when heart trouble made it impossible for him any longer to take an active role in his business. He died six years later.

IMPACT

Swan was a typical technological entrepreneur of the Victorian era: a "self-made man" who rose from poverty by virtue of his ingenuity and business acumen to win wealth and social advancement. Most of his innovations were relatively unspectacular and were lost to sight when they were superseded, and the one that made him rich and famous was overshadowed by the enormous reputation of a rival claimant. To this day, it is Edison rather than Swan who is almost universally, but somewhat unjustly, regarded as *the* inventor of the electric light bulb. It was Swan, however, who took out the first patent and subsequently matched his rival in terms of the redevelopment of the technology; his decision to join the Edison Company rather than attempting to beat it must be reckoned generous, especially as it left the United States entirely at Edison's disposal.

Although his fame and wealth arrived belatedly, partly because he labored so long in the unfashionable northeast corner of England, Swan was enabled to enjoy them by living to a ripe old age—which also enabled him to see many of London's streets and homes lit by his most celebrated invention. That presumably gave him a great deal of satisfaction, and justifiably so. The crucial role he played in facilitating the incorporation of photographic illustrations in books and magazines also made his influence widely felt, albeit indirectly, in Victorian public and private life.

—*Brian Stableford*

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Swan, Mary E., with Kenneth R. Swan. *Sir Joseph Wilson Swan, F.R.S., Inventor and Scientist*. Newcastle upon Tyne, England: Oriel, 1968. A reverent biography compiled by two of Swan's children, who had earlier collaborated on a memoir published by Ernest Benn in 1929. Kenneth also produced a shorter text, specifically focused on the electric lamp, for the British Council in 1948, but the substance of both earlier works is recapitulated here.

See also: Sir William Crookes; Thomas Alva Edison; Nikola Tesla; George Westinghouse.

LEO SZILARD

Hungarian American nuclear physicist

Szilard conceived the chain reaction necessary for a nuclear reactor or an atomic bomb. Szilard was a contributor to the Manhattan Project, which produced the first atomic bombs, used to end World War II.

Born: February 11, 1898; Budapest, Austro-Hungarian Empire (now in Hungary)
Died: May 30, 1964; La Jolla, California
Primary field: Physics
Primary inventions: Nuclear chain reaction; atomic bomb

EARLY LIFE

Leo Szilard (LEH-oh SEE-lahrd) was born to Louis and Tekla Spitz, a Hungarian Jewish couple. They changed their last name in 1900 to Szilard, meaning "solid," because of governmental pressure to change foreign-sounding names. Leo had a brother, Bela Szilard (later to be known as Bela Silard) and a sister, Rose Szilard. Since their father, Louis, was an engineer, the boys received solid training in mathematics and the sciences. Leo Szilard attended what would become the Budapest Technical University. During World War I, he was drafted into the army. As a college student, he was trained as an officer but was at home, sick with the Spanish flu, when his unit was sent to the front and demolished. The war ended before he recovered.

In 1919, Szilard went to Berlin to study electrical engineering but found physics so intriguing that he began to work toward a doctorate with Max von Laue. Although it was not the problem that he was assigned, Szilard worked out the mathematical proof that Maxwell's demon could not violate the second law of thermodynamics. One outcome of the second law is that it is impossible to create a perpetual motion machine. Maxwell's demon had to have knowledge (a "bit" of information) of the particles to sort them. This extra information would allow the sorting of particles. Szilard proved that because the information cannot be known, Maxwell's demon cannot generate a perpetual motion machine. This proof earned him a doctoral degree and was the cornerstone to the field of information theory that developed later.

Szilard became von Laue's assistant and later an assistant professor at the University of Berlin. During this time Szilard collaborated with Albert Einstein to invent a refrigerator with no moving parts. Although in seven years they designed three different types of refrigerators and received several patents, none of the refrigerators made it into public use. From this work, however, did come the Einstein-Szilard electromagnetic pump. The pump had no moving parts but instead used an electromagnetic field to push a liquid metal. In 1933, Szilard fled Nazism and Berlin for Vienna and then England. In 1937, he moved permanently to the United States.

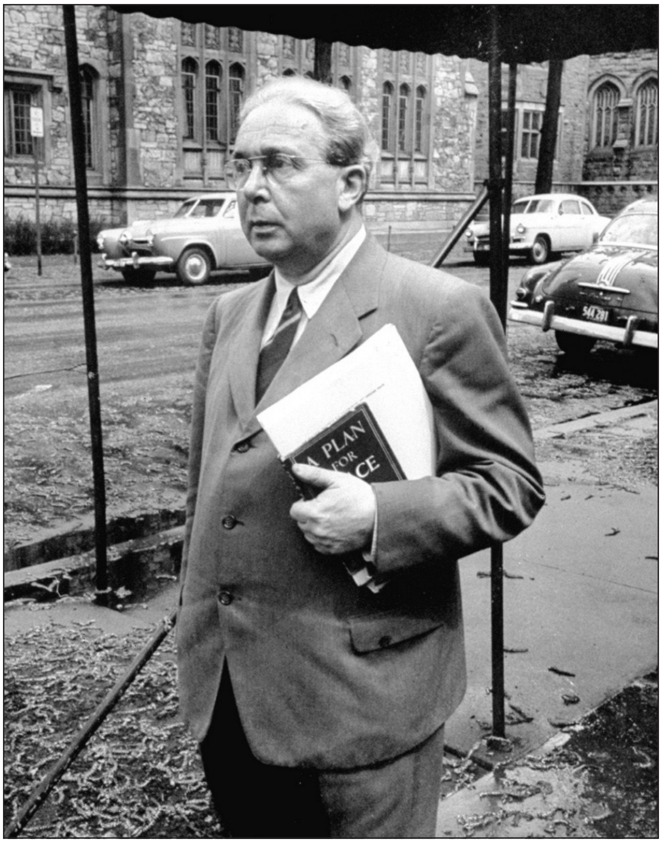
LIFE'S WORK

In 1933, Szilard conceived of the concept of a nuclear chain reaction. His thoughts were that it would produce the power needed for the modern world. He first considered beryllium and actually tested it and a few other elements to see if they would produce the chain reaction. In 1939, Szilard thought uranium would produce such a reaction after he heard of the fission of uranium reported by Otto Hahn, Fritz Strassman, and Lise Meitner. After testing the idea and hearing of the work by German scientists, he convinced Einstein to sign a letter that he wrote to President Franklin D. Roosevelt warning the president that German scientists were doing experiments that could lead to making a bomb of dramatic proportion. The letter resulted in a committee being formed and eventually the start of the Manhattan Project to build a bomb.

Szilard worked with Enrico Fermi in building the first nuclear reactor, which proved the concept of nuclear chain reaction. He was the person who arranged for boron-free graphite to be used as a component of the reactor. Normal graphite contains boron, which absorbs neutrons and slows the chain reaction. He continued to contribute to the Manhattan Project until the atomic bombs were completed.

After Germany surrendered, Szilard did not want the bomb to be dropped on Japan. He felt that a demonstration of its power would be enough. After the war, he worked for peace. He had always feared the power of nuclear weapons. He even tried to start peace talks with the Soviet Union. He wrote books such as *How to Live with the Bomb and Survive* (1960) and *The Voice of the Dolphin* (1961), a science-fiction look at how dangerous nuclear weapons can be. Szilard also began to work in 1946 on antibodies and on the regulation of enzymes.

On October 13, 1951, he married Gertrud "Trude" Weiss; however, they did not live together until his health began to fail in 1959. Szilard had met the Viennese woman in 1929 and was her mentor and longtime friend. He suggested that she attend medical school because he thought that she was, in his words, too dumb to be a physicist. They had traveled together in England in 1936 and several times in the United States. In the years before their marriage, he had often visited Trude. She worked as a medical doctor in New York, and after 1950, she taught at the University of Colorado Medical School. When Szilard was stricken with bladder cancer in 1959, he arranged for a new type of radiation treatment with Trude as his doctor. The radiation treatment was successful. In February, 1964, they moved to La Jolla, California, for Szilard to take a position at the Salk Institute. He died May 30, 1964, in his sleep, of a heart attack.



Leo Szilard. (Time & Life Pictures/Getty Images)

Szilard was a brilliant man who enjoyed exchanging ideas with others more than he enjoyed mundane everyday research. He knew how to do research but he wanted to supply the idea and sometimes the advice, yet have someone else do the day-to-day routine work. He liked to sit for hours in a bathtub, where he did some of his best work. His work schedule, or in some views, lack of work schedule, often meant that he had difficulty holding a paying position that offered the freedom that he wanted. His desire was to be able to travel to talk with other scientists. His position at the Salk Institute was his dream job.

The list of ideas that Szilard had is astounding. In 1923, he designed an X-ray sensor element. He next developed an improvement for mercury-vapor lamps for which the Siemens Company bought the licenses. In 1928, he patented a linear accelerator, independent of the design of Rolf Wideroe. A year before Ernest Lawrence built his cyclotron in 1929, Szilard patented a cyclotron and a betatron. All modern accelerators except for electrostatic machines are based on a combination of several ideas: multiple acceleration, focusing, frequency modulation, and phase stability. All of these were theories conceived by Szilard between 1928 and 1934. He also foresaw the electron microscope by 1928. While Szilard was in Berlin (1920-1933), he was granted thirty-one patents. The only patent that actually came to fruition was the "Discharge Tube to Be Used as an Electron Source." Szilard and Einstein designed and received several patents for three types of refrigerators: absorption, diffusion, and electromagnetic. The most successful idea in terms of use of the early collaboration of Szilard and Einstein was the Einstein-Szilard pump. Its inherent safety makes it valuable in cooling breeder reactors. In 1933, he conceived his most famous idea, the nuclear chain reaction. Shortly afterward, he worked with Thomas Chalmers using a neutron source to irradiate different samples. The results from this work became known as the Szilard-Chalmers reactions, or hot atom chemistry. His work with Chalmers allowed him to eliminate beryllium

HOT ATOM CHEMISTRY

In 1934, Leo Szilard and Thomas Chalmers developed the Szilard-Chalmers reactions, a method for concentrating artificially produced radioactive isotopes. The Szilard-Chalmers reactions are now often called "hot atom chemistry." By bombarding ethyl iodide with neutrons, the iodide absorbs a neutron, causing stable I-127 to become radioactive I-128, which emits a gamma ray. The recoil energy of the atom from the gamma ray is enough to break the chemical bonds and allow the I-128 to escape the compound. The separated I-128 can then be extracted with water and precipitated with silver ions. In this way, Szilard established a method to separate isotopes. If the right extraction is used, the method can produce a carrier-free isotope. If the temperature of the recoil energy is calculated, it is close to a million degrees, thus the term "hot atom" chemistry. A second advantage is that not all of the I-128 is extracted from the sample so it can be used as a medical tracer.

The Szilard-Chalmers reactions have been used with carbon 11 to study mechanisms of organic reactions. Carbon 11 has also been used extensively in diagnostic medicine. For example, the use of L-dopamine in the treatment of Parkinson's disease could be researched because of these reactions. The chemistry of germanium and silicon has been studied by using "hot atom" techniques.

and a few other elements as chain reaction candidates. In 1935, Szilard conducted a series of experiments on slow neutron absorption that proved him to be competent as a nuclear physicist. In 1939, he went to Columbia and worked with Walter Zinn to prove that neutron-induced fission of uranium did produce enough product neutrons, at least two, to make a chain reaction possible. Szilard and Fermi designed and helped build the first nuclear reactor. Szilard later designed a breeder reactor that would produce plutonium 239. Plutonium 239 could also be used to produce a nuclear chain reaction.

IMPACT

Without Szilard, the world might not have nuclear power. In the United States, 20 percent of all electricity is generated by nuclear power plants. In other countries, the use of nuclear power is even greater, producing 70 percent of the electricity for France. One-third of the electricity for Belgium, Sweden, Spain, and Switzerland is from nuclear power.

The breeder reactor is used more in other countries than in the United States. The breeder reactor produces new fuel for the next round of energy production while making energy to produce electricity. It uses the neutrons from the fissioning of uranium 235 to change uranium 238 to plutonium 239. This method was used to produce the plutonium for the atomic bomb tested at White Sands, New Mexico, and the atomic bomb dropped on Nagasaki, Japan.

—*C. Alton Hassell*

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See also: Enrico Fermi; Edward Teller.

TOYOICHI TANAKA

Japanese American biophysicist

Tanaka's discovery of the phase transition of polymer gels initiated a new field of research, making it possible for scientists to see microscopic changes in a macroscopic way. Because the "smart gels" respond to stimuli by expanding and contracting exponentially, they are valuable for use in a wide variety of applications.

Born: January 4, 1946; Nagaoka, Niigata Prefecture, Japan
Died: May 20, 2000; Wellesley, Massachusetts
Also known as: Toyo Tanaka
Primary field: Physics
Primary invention: Smart gels

EARLY LIFE

Toyoichi Tanaka (to-yo-ee-chee tah-nah-kah) was born in Nagaoka, Niigata Prefecture, Japan, on January 4, 1946, to Toyosuke and Shizu Tanaka. As a child, he enjoyed athletics and was competitive in swordplay, racing, and sumo wrestling. He played baseball in junior high school for a time before stopping to devote time to preparing for entrance examinations into a good high school. He graduated from the elite Hibiya High School in 1964 before entering the University of Tokyo. His growing interest in the sciences was due in part to the influence of his father, a chemistry professor. In 1968, Tanaka received a bachelor of science degree in physics, followed two years later by a master's degree, and in 1973 a doctor of science degree, all from the University of Tokyo. In 1970, Tanaka married Tomoko Tahira. The following year a son, Kazunori, a graduate student in physics at the Massachusetts Institute of Technology (MIT) at the time of his father's death, was born. In 1972, Tanaka began postdoctoral work in physics at MIT, working with Professor George Benedek. A daughter, Ayako, was born in 1974. In 1975, he joined the physics faculty at MIT, rising to the rank of professor (1982) and becoming the Morningstar Professor of Science (1997). During the 1980-1981 academic year, Tanaka was visiting professor at the Pasteur Institute in Strasbourg, France, and was the Rashmer lecturer at the University of Washington in 1987. He also contributed a number of articles to professional journals and was editor in chief of the periodical *Polymer Gels and Networks* in 1992.

LIFE'S WORK

Tanaka was only in his thirties when he made his first big discovery, that of the phase transition of polymer gels. Through his experimentation, he was able to make important theoretical predictions about polymers; in so doing, he gave birth to a new field of research. In the mid-1970's, he found that polyacrylamide gels had the ability to respond to minute changes in their environment—variations of temperature, light, magnetism, or electricity—by changing color or by expanding or contracting exponentially. Tanaka fine-tuned gels to undergo radical changes, or phase transitions, when they came in contact with chemicals or environmental variations. This ability to react radically to these environmental changes resulted in the polymer gels with which he worked being labeled "smart" gels.

Because of the properties of expansion and contraction, Tanaka's gels are ideal for a number of practical applications in varied fields, such as in medicine, industry, and agriculture. In medicine, for example, when the appropriate gels are exposed to electricity, they may undergo a thousandfold increase in volume that allows them to function as artificial muscles when they are set in motion by a particular electrical pulse. They can also be programmed to release insulin when glucose levels drop below a certain point and used in other controlled drug release products. The gels are also being used in such products as long-lasting sunscreen and eyedrops. In industry, the smart gels have proven to be effective in the cleanup of oil spills and in the absorption and immobilization of toxic waste because they act as giant sponges. They may also act as molecular filters of various kinds. The gels are useful in personal care items such as diapers and certain cosmetic products in which they can hold and then release ingredients such as fragrances in response to the pH level of the skin. Agricultural applications are numerous as well.

As Tanaka's research continued, he was able to elucidate the roles of the various chemical and physical forces found in natural and artificial polymers involved in the phenomenon of polymer folding, the process whereby a polymer's linear chair of molecules crumple, or fold, into more solid shapes so that they can perform their microscopic functions within living organisms. Putting this knowledge to practical use, Tanaka helped many scientists and companies to realize the practical applications of his work. In fact, in 1992, he cofounded GelMed, Inc.,

Smart Gels

Toyoichi Tanaka was recognized worldwide for his revolutionary discovery of smart gels, which is the phase transition in polymer gels. A gel is a polymer, a long chain of molecules, or monomers, which is cross-linked much like a web of fibers, giving it elasticity and fluidity. These links allow a gel to capture water. Smart gels are called “smart” because of their ability to expand, contract, or change color when they are exposed to even the slightest of variations of temperature, magnetism, light, or electricity. This ability of the gels to experience very large but reversible changes in volume make the gels ideal for a number of important applications in a number of fields, such as in chemistry, agriculture, medicine, and engineering. What material a gel interacts with determines what its behavior will be.

Thanks to Tanaka’s pioneering research, experimentation with smart gels, which are stimuli-responsive polymers, continues to search for practical applications in a wide variety of fields. Biomedical applications include such things as controlled drug release, ocular devices, and the synthesis of products by artificial mechanisms that mimic those in nature (biometrics). Agricultural applications include soil additives to conserve water, the coating of plant roots to increase water availability, and seed coating to increase germination rates. In industry, smart gel applications are numerous, and the future may well find many more.

Understanding the phase transitions of gels enables one to better understand the functions of proteins, which are the molecular basis of life. Proteins are made up of different sequences of twenty amino acids. Amazingly, these proteins can twist themselves into various shapes that they can “remember.” They are able to recognize particular molecules that they can store or release as needed, and, as such, they can assist in effecting life-sustaining chemical reactions. Scientists are able to determine the sequence of amino acids that make up a specific protein, but it remains for future research to determine how to make one from scratch.

At the time of Dr. Tanaka’s death in 2000, he was working on synthesizing a gel that possessed characteristics similar to those of proteins that could recognize a target molecule. His hypothesis was that this research could possibly produce a model, even if a crude one, of pre-biotic polymerization, a key step in the origin of life. The current theory, that in the early days of Earth amino acids in some primordial soup came together randomly in a sequence capable of sustaining life, was unsatisfactory to Tanaka. Given the possible working sequences of amino acids, he held that not all the possible combinations could have been tried, given the age of the universe. It remains for future scientists to discover all the potential applications of Tanaka’s smart gels.

and a sister company, Gel Sciences, Inc. These companies explored medical, cosmetic, commercial, and industrial applications for polymer gels. Tanaka later cofounded Buyo-Buyo, Inc., a company that concentrates on finding medical solutions for enhancing and extending human life. Of particular interest to him was the idea of using smart gels to build artificial muscles. In the latter years of his life, Tanaka focused his energies on trying to unravel the mysteries of the origin of life, with which he saw a direct connection with his gel research.

Tanaka was honored with a number of awards before his untimely death. While still in his thirties, Tanaka received the Nishima Memorial Prize in 1985, and the following year the Award of the Polymer Society of Japan. He became a fellow of the American Physical Society in 1992, and in 1993 he was awarded the Vinci d’Excellence in France. In 1994, he received the Inoue Prize for Science, awarded for his outstanding achievement in basic science and given annually to a scientist under age fifty. In 1996, he won both the R&D 100 Award and *Discover* magazine’s Editor’s Choice for Emerging Technology Award. In 1997, he was the winner of the Thirty-eighth Toray Science and Technology Prize from the Toray Science Foundation in Japan. He was a Nobel Prize nominee and was considered one of the frontrunners among Japanese scientists to win one in the future, had his life not been cut short.

Tanaka’s hobbies included jazz piano, guitar, shogi (Japanese chess), watching movies, reading, and tennis. On Saturday, May 20, 2000, he died of an acute myocardial infarction at age fifty-four, while he was playing tennis.

Impact

While the general public may have heard about Tanaka through his inventions and applications of his polymer gel research, especially that having to do with smart gels, it was his scientific research and discovery that may prove to have been his greatest contribution. Because of that research, countless numbers of later researchers, scientists, and inventors whom Tanaka himself never met may well benefit from his work for years to come. Nevertheless, it is undoubtedly his work with polymers, and his revolutionary discovery of smart gels in particular, that have assured him a lasting place in scientific discovery. The sheer number of practical applications as diverse as pollution-cleanup materials and cosmetics make his work important to an immensely wide variety of products.

In addition to Tanaka's work with polymer gels, he also contributed to the body of knowledge regarding the still-elusive process of polymer folding, the process by which polymers do not stay in the lengthened forms in which they begin but instead break into various solid shapes so that they can perform their microscopic functions within living organisms. Tanaka's elucidation of the roles, in polymer folding, of the various chemical and physical forces found in natural and artificial polymers led to numerous practical applications.

Not the least of Tanaka's impact on the world of science was his work with students; many of them considered themselves fortunate to be able to work in Dr. Tanaka's laboratory at MIT. He had the reputation of being a superb teacher who could hold students spellbound with his demonstrations.

In the final years before his death, Tanaka focused his energies on trying to unravel the mysteries of the origin of life. He could not accept the then current theory of the origin of life, and he died while pioneering a new frontier of science.

—*Victoria Price*

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See also: Sumio Iijima; Kary B. Mullis; Roy J. Plunkett.

CHARLES E. TAYLOR

American machinist and airplane mechanic

Taylor manufactured the aircraft engine used by the Wright brothers in 1903. He also built engines that powered their 1904 and 1905 airplanes and was the mechanic for the Wright Flying School at Huffman Prairie, Ohio.

Born: May 24, 1868; Cerro Gordo, Illinois
Died: June 30, 1956; Los Angeles, California
Also known as: Charles Edward Taylor (full name)
Primary field: Aeronautics and aerospace technology
Primary invention: Aircraft engine

EARLY LIFE

Charles Edward Taylor was born in the small town of Cerro Gordo, Illinois, to hog farmers Willet and Elmira Taylor. A hog cholera epidemic forced the family to move to Lincoln, Nebraska, in 1878. Taylor worked in a bakery and quit school after the seventh grade. At age twelve, he began work for the *Nevada State Journal* and worked his way into the bindery. It was here that he began his lifelong love affair with machinery. Taylor later claimed that the hog cholera epidemic was responsible for his career as a machinist.

As a young man, Taylor moved to California and worked briefly as a surveyor. Returning to Nebraska, he opened a machine shop. In 1892, he met Henrietta Webbert, and they were married two years later. In 1896, the Taylors moved to Dayton, Ohio, where Charles took a job with the Stoddard Manufacturing Company, a producer of farm machinery and bicycles. In 1898, he opened another machine shop where he did some subcontract work for Wilbur and Orville Wright. Coincidentally, Henrietta's family was familiar with the Wrights, and Henrietta's uncle owned the building in which the Wrights' bicycle shop was located.

Taylor sold his machine shop and accepted a job with the Dayton Electric Company but was soon hired as a full-time machinist by the Wrights. Taylor was aware that the Wrights were interested in gliders and flight, but he knew very little about airplanes or the brothers' flying activities. Taylor would later claim that he was hired as much for his management skills as for his machinist skills. Indeed, he managed the day-to-day affairs of the bicycle shop as the Wrights spent more time with their experiments, making trips to Kitty Hawk, North Carolina. This was to change when they returned from Kitty Hawk in 1901 and began construction of a wind tunnel for aerodynamic testing. Thus began Taylor's aviation career.

LIFE'S WORK

When the Wright brothers returned from Kitty Hawk in 1901, they recruited Taylor to assist in the construction of a wind tunnel to verify lift and drag calculations. He constructed balances for the machine by grinding down old hacksaw blades. After completion and testing of the wind tunnel, Taylor returned to managing the bicycle shop, leaving the aviation experiments to the Wrights. In 1902, the brothers announced that they were finished with glider experiments and desired to conduct powered flights. However, they met total resistance from engine manufacturers, who were unwilling or unable to construct an engine to meet the Wrights' specifications. The Wrights again turned to Taylor to manufacture an engine that would be light enough and powerful enough for their aircraft. Taylor was confident that he could manufacture such an engine, even though his only experience with engines up to that time was an attempt to repair an automobile engine in 1901. In six weeks, without any blueprints, and using only the limited machinery in the bicycle shop, he proceeded to manufacture the first successful aircraft engine.

The design and construction of this engine was critical to the Wrights' success. They calculated that the engine must weigh less than 180 pounds and develop at least eight horsepower. Working from hand-drawn sketches tacked to the machinery, Taylor constructed the engine. Since he kept no personal records, there is only limited information available about exactly how he manufactured the various parts. None of the original sketches have survived. What is known is that the original crankshaft was machined out of a hundred-pound block of tool steel and that the pistons and cylinder barrels were cast from a fine-grained iron. Taylor manufactured a number of duplicates for each part for constructing what he called a "skeleton model." This was a nonfunctional engine that was hooked up to the shop power system to verify the fit and proper operation of all the parts. Once Taylor was satisfied that everything fit and worked as expected, the actual engine was constructed.

Taylor's engine significantly exceeded the Wright brothers' specifications. It weighed 170 pounds, including all of the accessories, and produced twelve horsepower at 1,025 revolutions per minute (RPM). Taylor made use of readily available materials for construction. He built the radiator from metal speaking tubes commonly used in apartment houses, the ignition from components manufactured by Dayton Electric Company, and the fuel valve from a gas lamp. Taylor's vision and ingenuity was instrumental in the Wrights's historic flight on December 17, 1903, when they successfully flew a heavier-than-air plane at Kitty Hawk.

Taylor continued to design and build engines for the Wright brothers as their aircraft designs evolved. His 1904 engine developed eighteen horsepower. He integrated an automatic oiling system to prevent engine seizure. His 1905 engine was the first engine powerful enough to allow the carriage of a passenger. He built a thirty-two-horsepower engine for Army tests in 1907, and his successful 1909 military engine produced thirty-five horsepower. In addition to constructing engines, he machined metal fittings and helped assemble and rig the airplanes for flight. He accompanied the brothers to the military trials and accompanied Wilbur to France in 1907. Taylor was the only full-time employee of the Wrights until 1909, when they formed the Wright Company. At this point, Taylor was placed in charge of the engine shop.

Taylor apparently experienced some difficulty in the changing environment, and friction with the shop manager developed. This may have prompted him to accept a job with Cal Rogers in 1910. Rogers offered him $10 per day plus expenses to serve as his mechanic on a proposed cross-country flight. The Wright brothers wanted him to stay and convinced him to take a leave of absence rather than quit. Taylor accompanied Rogers to California, repairing the airplane after each of the many crashes en route. Because of his wife's ill health, Taylor decided to stay in California, where he worked for a number of early aviation pioneers, including Glenn Martin. After Wilbur Wright died in 1912, Taylor returned to Dayton and continued to work for Orville even after the company was sold. In 1919, Taylor accepted a job with the new Dayton Wright Company. He continued his association with the Wright Company and Orville, working with the company intermittently until 1928, when he moved back to California and virtually disappeared from the public eye.

Taylor did not reappear until he was approached by Henry Ford in 1937 to reconstruct the original Wright shop in Dearborn, Michigan. In this capacity, Taylor tracked down the original equipment, built a replica of the 1903 engine, and reconstructed the original shop. In 1941, he moved back to California, where he again seemingly disappeared. Taylor suffered a heart attack in 1945 and died in 1956 at the age of eighty-eight.

Impact

Taylor was a self-taught machinist with the ability to visualize how to manufacture an engine that could do what had never been done. Although he had limited experience with engines, he built the engine that made aviation possible. Without his insight and ability, the Wright brothers would not have flown successfully in 1903. He not only built the first successful aircraft engine but also improved it every year, allowing the Wright brothers to reach a level of performance that astonished the world. He is recognized by the Federal Aviation Administration as the world's first aircraft mechanic.

Due to his work managing the operations and flight school established by the Wrights at Huffman Prairie, Ohio, Taylor is also recognized as the first airport manager. He worked with many of the early pilots who flew for the Wright Exhibition Team. He was also instrumental in the success of the first transcontinental flight by Cal Rogers in 1911. During his sixty-year career as a machinist, he worked for a number of major aviation companies, including the Glenn L. Martin Company and North American Aviation.

Taylor is sometimes called aviation's forgotten man. He was a very private person, and many segments of his life remain undocumented. He did not seek the limelight or claim credit for the Wright brothers' success. He kept no personal records, and his essential contributions re-

The First Aircraft Engine

Charles E. Taylor was the first person to successfully address the problem of producing a satisfactory engine for powered flight. With no previous designs or experience on which to rely, and working with simple tools, he helped design, construct, and test the first practical aircraft engine. In six weeks, Taylor constructed an engine for aviators Wilbur and Orville Wright, exceeding their specifications. He produced virtually all the components himself in the brothers' bicycle shop.

Taylor claimed that this engine was the first four-cylinder aluminum block engine ever built. The crankcase was cast aluminum, and Taylor bored the cylinders on the shop lathe. Because of the limitations of the tools available, the water-cooled engine was mounted horizontally rather than vertically. The crankshaft was machined from a hundred-pound block of high carbon steel on which Taylor traced the outline of the shape he desired, drilled holes with the drill press, and knocked out the extra metal with a hammer. The engine had no throttle and employed a very simple carburetor system that vaporized the fuel, utilizing heat generated by the engine itself. This vaporized fuel was drawn into the cylinders through the open intake valve. Ignition was supplied by inducing a high-tension arc across platinum contacts within the cylinders. Initial ignition was supplied by a dry-cell battery, while a simple magneto supplied the current when the engine was running. Taylor incorporated a spark advance that actually retarded the ignition timing for ease of starting and a "kill switch" for grounding the magneto to shut down the engine. While these systems appear very primitive by today's standards, they were a giant step forward in 1903. Every component of the engine was designed to minimize weight without sacrificing the required power. The final product weighed 170 pounds and produced twelve horsepower.

While Taylor is remembered primarily for his 1903 engine, he continued to produce improved versions for the Wright brothers. He estimated that he built about six engines specifically for the Wrights, culminating with the 1909 "military version" that produced thirty-five horsepower. The Wright brothers recognized their debt to Taylor, and Orville Wright publicly credited Taylor for doing all of the machine work on the original as well as the succeeding experimental engines. Taylor's engine revolutionized the world of aviation on December 17, 1903, when the Wright brothers flew the first powered airplane at Kitty Hawk, North Carolina.

ceived little attention until the death of Orville Wright in 1948. After Orville's death, Taylor was awarded a number of honors in recognition of his lifelong contributions to aviation. In 1965, he was inducted into the National Aviation Hall of Fame. More than a footnote in aviation history, Taylor was a major supporting character to more widely known actors. His contributions throughout his life were vital to the perfection of the design of the modern airplane.

—*Ronald J. Ferrara*

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See also: George Cayley; Hans Joachim Pabst von Ohain; Andrei Nikolayevich Tupolev; Sheila Widnall; Wilbur and Orville Wright.

MARIA TELKES

Hungarian American biophysicist

Telkes made significant developments in the application of solar energy for practical use and is most notably attributed with designing the first solar home. Her primary research into phase-change thermal storage produced more than one hundred published papers, books, and numerous patents and inventions. The solar still and solar oven, two of her forward-looking inventions, are garnering renewed interest today in environmentally conscious circles.

Born: December 12, 1900; Budapest, Austro-Hungarian Empire (now in Hungary)
Died: December 2, 1995; Budapest, Hungary
Also known as: Maria de Telkes (birth name); Sun Queen
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Solar home; solar oven; solar stills

EARLY LIFE

Like most active teenagers in Hungary in the early 1900's, Maria Telkes (TEHL-kehs) spent much of her free time outdoors. Born on December 12, 1900, in Budapest, Austro-Hungarian Empire, to Aladar and Maria Laban de Telkes, she lived an active and full life. Her favorite outdoor activities were swimming, ice-skating, and sledding. Her enthusiasm for the outdoors was equally matched by her interest in the classroom and for her studies, in which she showed an increasing aptitude in science.

In high school, Telkes's imagination was stirred by reading a book titled *Future Sources of Power*. Inspired by what she read, she sought out more information, reading all the literature she could find pertaining to the Sun. She did not stop at her own Hungarian language, however; she continued reading in French, German, and English. While the book introduced ideas surrounding solar energy, they were largely still theoretical in her day.

However, Telkes in due course made practical what many had only imagined possible. It is not too much of a stretch to claim, then, that Telkes's lifetime quest to harness solar energy began with the reading of a book.

After high school, Telkes pursued studies in physical chemistry, receiving a bachelor of arts degree in 1920 and a doctorate of philosophy in 1924 from the University of Budapest. In her last graduate year, she gained experience teaching physics at a local Budapest high school. Encouraged by her early teaching experience, Telkes would return to work in academia repeatedly throughout her life.

Life's Work

Shortly after receiving her doctorate, Telkes visited the United States and stayed with her uncle, the Hungarian consul to Cleveland, Ohio. During this visit, she accepted a position as a biophysicist at the Cleveland Clinic Foundation, often working alongside one of its founders, Dr. George Crile. Their collaboration produced a book, *The Phenomena of Life* (1926), and led to the invention of a photoelectric device that recorded the brain's energy waves. Telkes applied herself diligently for the next twelve years at this post, where she studied cellular transformation, particularly as it applied to carcinogenesis, the development of cancer.

In 1937, Telkes initiated the first of many changes for her future career. She became a naturalized citizen of the United States and swapped her job and research direction by moving to Westinghouse Electric, where she studied heat energy. Possibly her many research interests or her past fascination with the Sun compelled her to restlessness, but whatever the impetus, Telkes changed positions frequently after her long stint at the foundation. Although she stayed at Westinghouse but two years, significantly, her new focus set her firmly on a path to discover practical ways to harness the Sun's energy.

Her new research direction started in earnest when Telkes joined the Solar Energy Conversion Project at the Massachusetts Institute of Technology (MIT) in 1939. The project's goal—to study energy conversion—had considered more conventional responses to store solar energy by heating bricks, rocks, concrete, or water. However, as a physical chemist, Telkes offered a novel but more appropriate response. Her solution recommended transforming and storing energy using a common and abundant material: Glauber's salt (sodium sulphate decahydrate). Inexpensive, plentiful, and nontoxic, Glauber's salt is derived from natural sources as well as from common by-products of chemical manufacturing processes. Traditionally used in the making of detergents, glass, and paper, it has a high heat storage capacity and melts when heated and solidifies (crystallizes) when cooled. Telkes discovered it was ideal as an energy conversion material because, when mixed with water, salt hydrates have a range of temperatures appropriate for solar storage systems: 85°-120° Fahrenheit for active systems, 70°-75° for passive systems, and 40°-65° for cooling. Making use of the material's phase-change capability, she proposed drawing ambient temperatures from the Sun during the day and outside air during the night to heat or cool a house as needed. Her solution, then, was inventive as well as economically ideal. Telkes's idea culminated in the building of the first solar house: the Dover House.

Taking note of Telkes's growing expertise with solar power was the U.S. government. Recruited during World

Maria Telkes adjusts the energy levels of the Dover House, the first solar-powered home, built in 1948. (Time & Life Pictures/Getty Images)

War II to prevent downed pilots from dehydration, Telkes, while working at the New York University College of Engineering Research Division, developed a solar still. Installed on life rafts, the still desalinated and demineralized the seawater using solar energy, making it fit for consumption. The solar still, constructed with several frames, made use of a weatherable Mylar film, painted black on a front surface-facing plate to absorb the Sun's energy. Later, Telkes was able to expand on her idea to design a large-scale solar desalinator in the U.S. Virgin Islands—a place chronically short of fresh water.

Throughout her life, Telkes continued research and development into solar application with an eye always toward utilizing practical and inexpensive materials. She developed a solar oven, intrinsically valuable to developing countries, and helped design materials used in the Apollo and Polaris space ventures to protect instrumentation from extreme temperatures. Recognized for her achievements, Telkes received the Certificate of Merit in 1945 from the Office of Scientific Research and Development for her solar still design. In 1952, she accepted an Achievement Award from the Society of Women Engineers and was recognized with the Greely Abbot Award by the International Solar Energy Society. In 1958, the Ford Foundation awarded her a grant of $45,000 to develop her solar oven design. In 1977, for her pioneering work in solar-heated technology, Telkes joined the ranks of previous honorees such as Frank Lloyd Wright in being recognized by the National Academy of Sciences Building Research Advisory Board.

Telkes received emeritus status in her last academic post from the University of Delaware. Beginning and ending her career in academia, Telkes retired from active research in 1978 but continued to consult on solar energy matters into the 1990's. Telkes died in 1995 just shy of her ninety-fifth birthday, while visiting the place of her birth, Budapest.

IMPACT

Today, with dwindling natural resources, appreciation of Telkes's early contributions to solar technologies may substantially increase, as her designs are proving to have far-reaching environmental application and relevance. The demand for solar stills and solar ovens has increased, particularly in developing countries and densely populated cities, where the availability of natural resources is becoming increasingly scarce.

The solar oven is in wide use and acceptance in parts of Africa. Recognized as an implement to help combat rampant deforestation, the inexpensive and practical functionality of the solar oven replaces traditional methods that employ wood fuel for cooking. Additionally, the device frees many people, typically women, from time-intensive chores. Where wood traditionally has been the only fuel available, its use leads to desertification of the surrounding area, and the

THE FIRST SOLAR-POWERED HOME

In 1948, Maria Telkes's solar-heating and cooling system reached fruition in the building of the first solar-powered home. Commissioned by Amelia Peabody, designed by Telkes along with architect Eleanor Raymond, and named after its location on Peabody's property in Dover, Massachusetts, the Dover House was situated on the grounds to maximize the full potential of the Sun's rays. Incorporated within the building's walls was Telkes's phase-change thermal storage system. The home's black-painted glass walls concentrated the sunlight and directed the heat via air into bins that contained a mixture of sodium sulphate decahydrate, silica, and Borax. To maintain the viability of the energy storage system, and to prevent issues related to the gravitational settling of salts, Telkes added the agents of silica and Borax to the salt solution to inhibit its nucleating capability and decomposition by bacteria or enzyme action.

Telkes lived in the Dover House comfortably for a couple of months, and for several years records were kept to monitor the temperature of the five rooms. Relatives resided in the home for three years and claimed that the passive solar-heating and cooling system kept the home at a comfortable 70° Fahrenheit, even during the coldest and hottest season of the year. No auxiliary heating or cooling was required. After three years, the system failed, but her experimentation with solar energy continued on. In total, Telkes designed three solar-powered homes.

During the 1950's and 1960's, development of passive solar-heated house designs continued with homes pioneered in the United Kingdom, Canada, and Japan. In 1973, the University of Delaware built the first solar-powered demonstration house, Solar One. In her senior position at the university, Telkes developed the solar laboratory's heating system. Solar One, however, departed from previous solar house designs to use photovoltaics (PVs) to directly convert sunlight into both heat and electricity. Gradually, thin PV designs replaced passive solar-heated systems in research and development, funded largely by the government and prompted in part by the energy crisis of the 1970's. Around the world today, passive solar energy (radiant heat) designs outnumber PV implementations.

resulting effects are often a dwindling water supply. Generally, when water becomes a limited commodity, conflict over rights of access normally follows. However, the solar still may help alleviate this problem in many areas as it makes available adjacent expanses of previously nonpotable seawater for consumption. In many ways, the applicability of Telkes's inventions promotes peaceful relations in a world that increasingly is finding that its available resources often outstrip its consumption.

Today, laws prohibit inequality in the workplace, but in Telkes's day women often had to overcome entrenched, patriarchal views concerning their role in science and engineering. Specifically, solar energy innovations often received less attention and funding than their nuclear counterpart because, as Telkes claimed, "Sunshine isn't lethal." Characteristically, then, women's contributions to science and innovative technologies were often ignored or given scant notice in gender-biased annals. However, thanks in large part to scholars in feminism, Telkes's contributions, and those of other women, are receiving current acknowledgment. In years to come, society may discover that it owes a further debt to Telkes's imagination and determination to harness the Sun's energy. For now, Telkes's lifetime commitment to solar application deservedly earns her the title of the "Sun Queen."

—*Jane R. Watson*

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See also: Calvin Fuller; Stanford Ovshinsky; Gerald Pearson.

EDWARD TELLER

Hungarian American physicist

Teller is frequently called "the father of the hydrogen bomb" because he played a major role in its design, development, and political acceptance.

Born: January 15, 1908; Budapest, Austro-Hungarian Empire (now in Hungary)
Died: September 9, 2003; Stanford, California
Also known as: Ede Teller
Primary field: Physics
Primary invention: Hydrogen bomb

EARLY LIFE

Edward Teller was born on January 15, 1908, to a Jewish family in Budapest, a major cultural center of the Austro-Hungarian Empire. His parents, Max Teller, a lawyer, and Ilona (Deutsch) Teller, a pianist, were well-educated and affluent. Edward was educated in private schools, and he showed talent in mathematics at a young age.

The breakup of the Austro-Hungarian Empire at the end of World War I happened when Teller was only ten years old. Political turmoil, as Hungary became indepen-

Edward Teller. (Lawrence Radiation Laboratory/AIP Niels Bohr Library)

dent, disrupted Teller's education. In 1926, Teller went to Karlsruhe, Germany, where he studied chemical engineering. He arrived in Germany just as a major new idea of physics, quantum mechanics, was developing. This highly mathematical technique to predict the behavior of microscopic particles appealed to Teller, who transferred to the University of Munich to study physics in 1928.

Teller's right foot was cut off in a streetcar accident later in 1928. After learning to walk with an artificial foot, he transferred to the University of Leipzig. Teller studied under Werner Heisenberg, one of the major figures in the development of quantum mechanics. In 1930, Teller was awarded a Ph.D. in physics. His thesis provided the first accurate quantum mechanical description of the "hydrogen molecular ion," a "three-particle system"—two hydrogen nuclei bound together by a single electron.

After receiving his Ph.D., Teller worked at the University of Göttingen, in Germany, for two years, but the rise of the Nazi Party made Germany unsafe for Jews. Assisted by the Jewish Rescue Committee, Teller left Germany in 1934. He went to London and then to Copenhagen, where he worked with Niels Bohr, another pioneer of quantum mechanics. George Gamow, a Russian physicist who Teller had met in Germany, persuaded George Washington University in Washington, D.C., to offer Teller a position in the Physics Department. Teller and his wife, "Mici" (Augusta Maria) Harkanyi, whom he married in February, 1934, moved to the United States. Teller worked with Gamow on problems in quantum, molecular, and nuclear physics until 1941. That year, Teller and his wife became naturalized American citizens.

LIFE'S WORK

In 1939, Teller and Hermann Arthur Jahn discovered the Jahn-Teller effect, which helps describe the chemical reactions of metals. The outbreak of World War II brought about a shift in Teller's interests from theoretical physics to the more applied areas of nuclear energy and weapons development.

In 1942, J. Robert Oppenheimer organized a meeting at the University of California, Berkeley, that resulted in the Manhattan Project, the code name for the U.S. effort to develop the atomic bomb. Research in Europe showed that a uranium atom could fission, breaking apart into two smaller atoms in a process that released energy. If enough energy was released in a short time, nuclear fission could be used in a powerful bomb.

Before Oppenheimer's meeting, Teller met with Enrico Fermi, who suggested that an atomic bomb might be used to produce the high temperature and pressure needed to fuse two very light atoms together, a process accompanied by an even bigger release of energy than could be achieved through fission. Although Teller first thought Fermi's idea would not work, he quickly became intrigued by this superbomb and described it at Oppenheimer's meeting.

A laboratory, directed by Oppenheimer, was established at Los Alamos, New Mexico, in 1943 to design and build an atomic bomb. Teller joined the Theoretical Physics Division of the Los Alamos National Laboratory in April of that year. He contributed to the understanding of implosion, a process that uses carefully shaped explosive charges placed around the outside of an object to compress the material inside. However, Teller's real interest was the superbomb. The first atomic bombs developed at Los Alamos were equivalent to about fifteen to twenty thousand tons of the chemical explosive trinitrotoluene (TNT), while Teller's superbomb, the hydrogen bomb, could have one thousand times that yield. The hydrogen bomb project was of low priority, however, at least until the atomic bomb was perfected.

In 1946, Teller again presented his idea for a hydrogen bomb. It used deuterium, a heavy isotope of hydrogen, as the fuel. However, other physicists thought Teller was too optimistic in assessing the feasibility of this design, which would require a very high temperature to initiate fusion. The suggestion that adding tritium, a heavier, radioactive isotope of hydrogen, to the deuterium would lower the required temperature was deemed reasonable. Unfortunately, the amount of tritium (which is very rare) required was unknown. Although Teller believed that the hydrogen bomb could be developed, the U.S. government did not proceed with the project. Disappointed, Teller left Los Alamos and accepted a position at the University of Chicago, where he worked with Fermi.

In 1948, after the Soviet Union tested its first atomic bomb, President Harry S. Truman decided to support the development of the hydrogen bomb. Teller went back to the Los Alamos laboratory in 1950, anxious to work on the development of his superbomb, but he soon became frustrated by the slow progress being made on the project. Calculations by mathematician Stanislaw Ulam showed that much more tritium would be needed than Teller had estimated, and the production of the isotope was slow and expensive.

In 1951, Ulam had an idea that allowed Teller to design a hydrogen bomb. With a feasible design, the Los Alamos group was able to test a hydrogen "device," technically not a bomb because it was too large and heavy (eighty-two tons) to be carried by any airplane. The test, codenamed "Ivy Mike," was conducted on November 1, 1952, on the small island of Elugelab in the Enewetak Atoll in the Pacific Ocean. The bomb had a yield equivalent to 10.4 million tons of TNT, almost completely vaporizing Elugelab.

By then, Teller had left Los Alamos, disappointed that he had not been chosen to head the development effort. He moved to California, where the nation's second nuclear weapons laboratory, now the Lawrence Livermore National Laboratory, had just been established. Rather than viewing the blast from the test site in the Pacific, Teller observed the shock wave from Ivy Mike in Berkeley on a seismograph, a device usually used to record the ground tremors from earthquakes. He knew immediately that the test was successful. The first hydrogen bomb, code-named "Castle Bravo" and designed at Los Alamos, was tested at the Bikini Atoll in the Pacific Ocean

THE HYDROGEN BOMB

The hydrogen bomb generates energy by nuclear fusion, the same process that generates energy in the Sun. In nuclear fusion, two light ions come together to produce a single, heavier ion. If the heavier ion has a mass less than the sum of the masses of the two ions that came together, then the excess mass is given off as energy.

Nuclear fusion requires extremely high temperature and pressure, or else the two ions cannot come together because of the repulsive force of their positive charges. Edward Teller recognized in 1943 that a fission bomb could provide both heat and compression needed to trigger a fusion reaction. It took a decade to develop the idea into a practical design, so that the fission would trigger the reaction rather than just blowing the fusion fuel apart. Teller developed an idea from Stanislaw Ulam, who recognized that much of the energy from a fission bomb is released as X rays. He suggested the fission and fusion parts of the hydrogen bomb could be kept separate from one another, and the X rays from fission could produce the high temperature and pressure necessary to trigger the fusion reaction. X rays, which travel at the speed of light, would reach the fusion fuel faster than the shock from the fission explosion, providing the critical time needed for fusion reactions to release energy. To increase the X-ray intensity, those X rays emitted away from the fusion fuel would be reflected by a casing surrounding the bomb.

The Teller-Ulam design remains classified. It is believed to consist of a fission bomb located inside the reflector. Deuterium and tritium are generally used as the fuel for a fusion bomb, but both are gases at room temperature. For the "Ivy Mike" test in 1952, the gas was cooled to liquid helium temperature, so it was liquid. However, the fusion device was too heavy, so later tests combined deuterium with lithium, since lithium deuterate is solid at room temperature. Heat from the X rays exerts pressure on the lithium deuterate, compressing it to less than one-tenth its original volume. Neutrons, also produced in the fission bomb, react with the lithium, producing tritium, which lowers the temperature needed to initiate fusion. Tritium-deuterium and deuterium-deuterium fusion reactions produce additional heat, radiation, and neutrons, continuing the reaction for as long as fifty-billionths of a second, long enough to result in a large release of energy. The Ivy Mike device employed the Teller-Ulam design, producing about seven hundred times the explosive power of the first atom bomb test.

on March 1, 1954. The Livermore laboratory tested its first hydrogen bomb at Bikini a month later, on April 7, 1954.

Teller's testimony during congressional hearings on the renewal of Oppenheimer's security clearance, in 1954, alienated him from some of his colleagues. Although Teller testified that Oppenheimer had provided excellent leadership in developing the atomic bomb, he indicated that Oppenheimer hindered the effort to develop the hydrogen bomb. The Atomic Energy Commission (AEC) did not renew Oppenheimer's security clearance, citing in part his opposition to thermonuclear weapons.

Teller was named director of the Lawrence Livermore National Laboratory in 1958, but he resigned in 1960 so he could lobby against a proposed ban on testing nuclear weapons, testifying before congressional committees, appearing on television, and writing on the issue. Teller advocated the use of nuclear technology to solve a variety of military and civilian problems. He proposed excavating an artificial harbor by using nuclear explosions, to ship coal and oil from Cape Thompson, Alaska. The AEC adopted this plan, called Project Chariot, which would have exploded six hydrogen bombs in Alaskan waters. Project Chariot was canceled, however, because local residents and Alaskan political leaders were concerned about the possible radiation hazard.

Teller spoke out strongly in favor of President Ronald Reagan's Strategic Defense Initiative, a proposal to intercept and destroy intercontinental ballistic missiles using intense X-ray lasers, powered by nuclear explosions, which would have been deployed on orbiting satellites. He also advocated development of a system that would have used nuclear explosions to intercept and destroy asteroids on a collision course with Earth. Teller suffered a stroke and died in Stanford, California, on September 9, 2003.

IMPACT

Teller's work on implosion technology was important to the development of plutonium-based atomic bombs. This type was first tested in New Mexico in 1945 and dropped on Nagasaki, Japan, bringing an end to World War II.

Teller developed the first practical design for the hydrogen bomb and was instrumental in convincing the U.S. government to open a second nuclear weapons laboratory, Lawrence Livermore National Laboratory, to more rapidly develop that bomb. His hydrogen bomb ushered in a half century without world war, as the world's superpowers recognized that the use of hydrogen bombs would guarantee the destruction of both nations, a policy called "mutual assured destruction."

Teller exerted influence on defense and energy policies in the United States, writing more than a dozen books on these topics. As chair of the Reactor Safeguard Committee of the AEC in the late 1940's, he helped develop nuclear reactor safety standards. Teller lobbied against nuclear test bans, and for nuclear power, particularly nuclear fusion, and the Strategic Defense Initiative, but he never succeeded in overcoming public skepticism about nuclear power.

—*George J. Flynn*

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See also: Enrico Fermi; Ernest Orlando Lawrence; J. Robert Oppenheimer.

NIKOLA TESLA

Serbian American engineer

Tesla spent his life researching new ideas in theoretical physics, electricity, and magnetism in the late nineteenth and early twentieth centuries. Although his brilliance was later obscured by mental illness, Tesla's work has dubbed him the "inventor" of the twentieth century.

Born: July 9/10, 1856; Smiljan, Austro-Hungarian Empire (now in Croatia)
Died: January 7, 1943; New York, New York
Primary fields: Electronics and electrical engineering; physics
Primary inventions: Rotating magnetic field applications; induction motor; arc lighting; alternating-current transmission; transformer; wireless communication systems; power-transmission systems

EARLY LIFE

Nikola Tesla (NIH-koh-luh TEHS-luh) was one of five children born to the Reverend Milutin Tesla, a priest in the Serbian Orthodox Church Metropolitanate of Sremski Karlovci, and Đuka Mandić, herself a daughter of a Serbian Orthodox Church priest, in the village of Smiljan, Austro-Hungarian Empire (present-day Croatia). He was born at midnight between July 9 and 10, allegedly during an electrical storm.

As a child, Tesla was expected to become a minister like his father. His natural talents, however, caused Tesla to dream of pursuing a scientific career. He was born with a prodigious memory, could perform calculations in his head, and had the ability to visualize scenes, people, and objects vividly. This dream, however, seemed unreachable because of his father's expectations.

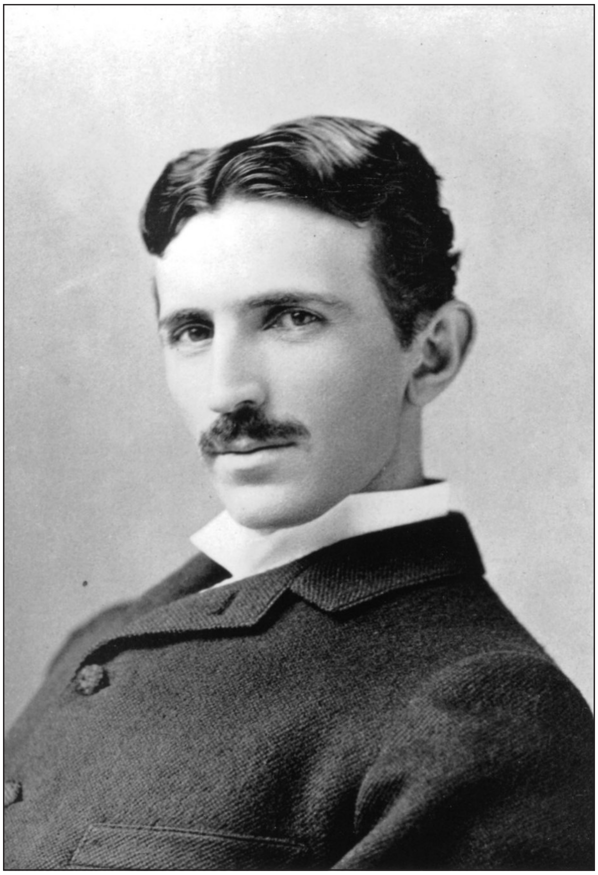
Fortunately, after graduating from the *Realgymnasium* in Austria, Tesla caught cholera and became gravely ill. Fearing that his son was dying, Milutin Tesla promised his son that he would allow him to attend engineering school if he would recover. Given Nikola Tesla's tremendous strength of will, it should not be a surprise that he survived, and he attended the Austrian Polytechnic School at Graz in 1875.

While at university, Tesla studied the uses of alternating current (AC), but a scholarship that had enabled him to attend classes was eventually terminated, a situation that Tesla exacerbated by a growing love of gambling. Tesla never officially returned to school beyond the first semester of his third year. In December of 1878, he left Graz.

By 1881, Tesla was working for a telegraph company in Budapest and finally able to begin his lifelong love of invention. He developed a type of telephone repeater or amplifier, a precursor to the modern loudspeaker. Although his work with Nebojša Petrović, a fellow inventor, resulted in several designs for a twin-turbine-powered engine, he wanted to work more definitively as an inventor and signed up with the Continental Edison Company in Paris, France. By the end of 1882, Tesla had conceived the earliest ancestors of what would become his most well-known invention, the induction motor, and began developing various devices using rotating magnetic fields.

LIFE'S WORK

On June 6, 1884, Tesla traveled to New York City with nothing in his pockets but a few cents and a letter of rec-



Nikola Tesla. (Library of Congress)

ommendation from his former manager Charles Batchelor addressed to American inventor Thomas Alva Edison. Impressed, Edison hired Tesla to work for the Edison Machine Works, beginning with simple electrical engineering and eventually becoming a troubleshooter for Edison's most complex engineering issues. Tesla's salary was a modest $18 per week; he was angered at Edison's dismissal of his value and promptly resigned when Edison would not offer him a raise.

After a brief stint digging ditches from 1886 to 1887, Tesla finally attracted the attention of wealthy inventor George Westinghouse and began the process of creating the initial brushless AC induction motor with his financial support. It was sufficiently ready in 1888 to demonstrate to the American Institute of Electrical Engineers (AIEE; later merged into the Institute of Electrical and Electronics Engineers, or IEEE). Tesla's design for a polyphase system transmitting electricity wirelessly further impressed Westinghouse, and he offered Tesla a position at the Pittsburgh laboratories at Westinghouse Electric and Manufacturing Company.

In 1891, while becoming a naturalized U.S. citizen, Tesla demonstrated what came to be called the "Tesla effect," the wireless transmission of electrical energy based on electrical conductivity. He moved his scientific experiments to 35 South Fifth Avenue in New York, and later to 46 E. Houston Street, much to the disgruntlement of his neighbors. Experimenting with sound resonances, Tesla accidentally discovered the vibrational frequency of his apartment building and several of the ones around it, causing them to violently shake on their foundations. Summoned by Tesla's terrified neighbors, the police encountered a calm Tesla surrounded by the crushed remains of his device; he had been forced to take a sledgehammer to his invention.

When he was thirty-six years old, Tesla's first patents for a polyphase power system were granted, encouraging him to further develop uses for alternating current. The 1893 World's Fair in Chicago showcased his wireless electric lights by allowing Tesla to illuminate the various buildings with his fluorescent lamps. His "Egg of Columbus," a sphere made of copper, stood on end as a demonstration of the rotating magnetic field principle. Despite his successes, however, Nikola Tesla's AC generator was made to directly compete with Edison's direct current (DC) motors for development funds. Because of this "War of Currents," Edison and Westinghouse suffered near financial ruin, forcing Tesla to tear apart his royalty contracts with Westinghouse.

By 1899, Tesla decided that his current quarters were inadequate to the task of housing his experiments with high voltage and high frequencies. He moved his research to Colorado Springs, Colorado, where he demonstrated the conductivity of the Earth and generated ball lightning. He was still researching wireless technology,

The Rotating Magnetic Field Principle

A magnetic field, as defined by physics, is a field produced by moving electric charges that form currents, or waves. The charges exert a force on other moving charges. A magnetic field associates with every point in space a vector that may vary in time; hence, it is a vector field. A magnetic field affects the movement of magnetic dipoles and electric charges. It permeates space, surrounding all electrically charged objects, and exerts a magnetic force. Magnetic fields can be generated in a variety of ways, both through natural and artificial processes, and have an energy density proportional to the square of the field intensity. Stationary dipoles generate magnetic fields that are constant. Changing electric fields, one of the basic principles of electromagnetism, generate rotating magnetic fields.

Nikola Tesla discovered the rotating magnetic field as a precursor to his work on devices using alternating current (AC). Alternating current is so named because its magnitude and direction change frequently in a cyclical motion, rather than remaining constant like the electrical currents generated by the stationary fields created by direct current (DC) generators. The rotation of magnetic fields creates an electric impulse that is both efficient and cost-effective to transmit as a sine wave. Tesla adapted this principle in order to realize his vision of his induction motor and a polyphase system that not only can create electrical energy but also can transmit it efficiently and over vast distances by both cable conduction and, potentially, without wires using energy generated by the movement of the molten center of the Earth's core and conducted through the magnetic lines that make up the Earth's magnetic poles.

The AC induction motor continues to be used as the basis of consumer electronics and industrial machines. It formed the basis for the Industrial Revolution, since the polyphasic AC system is a highly adaptable method of powering everything from toasters to table lamps. Some examples of the many uses of AC are audio and radio signals. These devices emphasize the importance of data integrity, since inefficient transmission would reduce an audio or radio signal to incomprehensible babble.

and he found that the resonant frequency of the Earth was approximately 8 hertz.

Despite his many patents, Tesla was continually troubled by the lack of funding. On January 7, 1900, he was forced to sell his laboratory equipment and leave Colorado Springs. Still hopeful of a more successful future, Tesla built the Wardenclyffe laboratory and its famous transmitting tower in Shoreham, Long Island. The tower, copper-domed and 187 feet high, was intended to transmit both signals and power without wires to any destination. Unsure of the profitability of such an invention, however, financier J. P. Morgan pulled his monetary support. The unfinished tower would remain standing until 1917, when the U.S. government decided that it was a national security risk and that the land it sat on would be more valuable without the tower.

Tesla's troubles continued to plague him. The rent on his two-room suite at the Waldorf-Astoria Hotel had been deferred because of a private agreement between Tesla and proprietor George Boldt, but mounting financial pressure forced Tesla to turn over his Wardenclyffe deed to pay the $20,000 he owed. Ironically, in 1917 Tesla established principles regarding frequency and power level for the first radio detection and ranging (radar) units and received AIEE's highest honor, the Edison Medal.

By 1943, Tesla was penniless and his life constricted by his ever-worsening phobias. His behavior, always marked by eccentricity, became bizarre. He became known for taking care of Central Park's pigeons, often taking injured ones home. He died of heart failure in Room 3327 of the New Yorker Hotel, but his reclusive nature made the exact day difficult to determine. One of the last times Tesla was seen alive, an assistant discovered Tesla standing in front of his open window in the middle of an electrical storm, feverish and claiming that he had made better lightning than God. It was later discovered that Tesla had died between the evening of January 5 and the morning of January 8, the constant effect of electricity upon his body having finally caused his heart to fail. Tesla never realized significant profits from the sale of his many patents, even though the ones describing AC electricity were extremely valuable. Nevertheless, his longtime feud with Guglielmo Marconi, who had successfully challenged Tesla's patent on the principles of radio and been awarded the Nobel Prize in Physics for radio in 1909, was ended with the U.S. Supreme Court establishing Tesla as the inventor of radio, recognizing the validity of Tesla's U.S. Patent number 645,576 (1893).

Tesla's funeral was held at Manhattan's Cathedral of St. John the Divine on January 12, 1943, and the inventor's remains were cremated and enshrined in a golden sphere. Immediately thereafter, in spite of Tesla's status as a naturalized citizen, the government's Alien Property Custodian Office was directed by the Federal Bureau of Investigation (FBI) to impound Tesla's possessions in the hopes of recovering a so-called death-ray based on Tesla's experiments with controllable ball lightning and plasma. Although no such device was found, Tesla's papers were taken, and the War Department decided to classify his research as "top secret." Tesla's family and the Yugoslav embassy struggled to prevent the confiscation. Eventually, his nephew, Sava Kosanović, was able to reclaim Tesla's cremated remains as well as some of Tesla's personal effects and placed them on permanent loan to the Nikola Tesla Museum in Belgrade, Serbia.

IMPACT

Tesla was one of those rare individuals whose contributions to society defy any attempt at summary. He acquired more than seven hundred patents both in the United States and in Europe on a wide variety of topics. Some of the consequences of his work were the creation of the Nikola Tesla Award by the IEEE and the naming of the SI unit for measuring magnetic flux density (or magnetic induction), the tesla. He has been extensively recognized in his homeland, even though he is relatively unknown in the United States outside the field of electrical engineering.

It is hard to imagine what the world would be like if Tesla had not survived cholera in 1875. He was directly responsible for so many "fixtures" of modern life—such as AC electricity, radio, radar, and X-ray photography—that one cannot really comprehend how differently modern technology might have arisen. There have been a few monuments created to honor this brilliant man; his close friend Ivan Meštrović made a bust of him when the sculptor was in the United States. The artwork, finished in 1952, became the centerpiece of the Tesla exhibit in the Nikola Tesla Museum in Belgrade. Another statue was placed on the aptly named Nikola Tesla Street in Zagreb's city center on the 150th anniversary of Tesla's birth, with a duplicate erected at the Ruđer Bošković Institute. Finally, in 1976, Niagara Falls commissioned a bronze statue of Tesla. It remains to be seen if Tesla's creative genius can overcome the obscurity to which his work has been condemned.

—Julia M. Meyers

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See also: Thomas Alva Edison; Michael Faraday; Reginald Aubrey Fessenden; Guglielmo Marconi; Elihu Thomson; George Westinghouse.

VALERIE L. THOMAS

American aerospace administrator, analyst, and electronics designer

Inventor of the illusion transmitter, Thomas worked for NASA as a mathematical data analyst and as project manager for NASA's image-processing system on Landsat.

Born: February 1, 1943; Baltimore, Maryland
Primary fields: Aeronautics and aerospace technology; electronics and electrical engineering
Primary invention: Illusion transmitter

EARLY LIFE

Valerie L. Thomas showed an early interest in technology, and at age eight she checked out from the library *A First Electrical Book for Boys* (1935) with the idea that her father would help her build some of the models it provided. Although he did not aid her in this specific endeavor, she was not discouraged. Thomas's parents did encourage her interest, which she learned from her father. She continued to explore electronics during her childhood. Her father taught her how to take a radio apart and reassemble it, explaining the function of each part. She even worked on some of her neighbors' broken electronics in her youth. As electronics advanced, Thomas continued to learn, and she was able to work on early televisions as well.

Thomas pursued her interest in technology and science at her all-girls high school, where she ranked at the top of her class. Though the school did not offer electronics classes and she did not take the advanced math classes that were offered, teachers supported her with additional projects that would promote her interest in math and science. After high school, Thomas attended Morgan State College (now Morgan State University) in Baltimore, Maryland, where she was one of only two women to major in physics. She would later receive a doctorate in education at the University of Delaware in 2004. Her dissertation focused on a method to improve teaching mathematics to middle school students.

LIFE'S WORK

In 1964, Thomas was offered a job at the National Aeronautics and Space Administration (NASA). She began her career with NASA in mathematical and data analysis. From 1964 to 1970, she worked creating real-time, quick-look processor data systems for the Orbiting Geophysical Observatory (OGO) and Multi-satellite Operations Control Centers. Following this work, from 1970 to 1980, she filled many other roles for NASA, including serving as assistant director of the National Space Science Data Center (NSSDC). In this position, one of her jobs was to develop a pipeline-processing software data system; this work sustained the launch of three Landsat Earth-observing satellite systems.

Thomas became an international expert on Landsat digital products. From 1984 to 1985, she was assistant project manager for the Pilot Land Data System. She also worked at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, as leader for the multi-agency Large Area Crop Inventory Experiment (LACIE). This project included members from NASA, the National Oceanic and Atmospheric Administration (NOAA), and the United States Department of Agriculture (USDA). The LACIE project, comprising around fifty members, predicted global wheat crop yields based on weather patterns.

The years between 1986 and 1990 found Thomas managing the Space Physics Analysis Network (SPAN) and the NASA Automated Systems Incident Response Capability Team, as well as working at the Space Science Data Operations Office (SSDOO). She served as technical officer SSDOO's Hughes STX On/Offsite technical support contract and led the SSDOO's Education Committee. Her work on the creation of data and information systems for NASA was unequaled and led to her appointment as associate chief of the SSDOO. It was from this position that she retired in August, 1995. In addition to her work in these groups, Thomas designed computer programs that facilitate the study of astronomical phenomenon such as Halley's comet, supernova explosions, the ozone layer, and other planets.

Thomas received varied awards and honors during her career. In 1984, she served as president of the National Technical Association (NTA), the oldest predominantly African American technical association. She was awarded the GSFC Award of Merit and the NASA Equal Opportunity Medal for individual achievements. She also received the NASA Group Achievement Award on April 12, 1995, for her work on the LACIE project.

Thomas's work was so admired that she filled a managerial position in NASA's image-processing systems for Landsat. In this position, her inventions made it possible for pictures to be sent to Earth from space. The idea behind Thomas's illusion transmitter was to improve the space images being sent from Landsat. The illusion transmitter takes two-dimensional pictures seen on a screen and turns them into accurate three-dimensional images that are suspended in space. The basic concept of the invention is similar to that of television, employing signals that travel through the air.

The inspiration for the illusion transmitter came partially from an experiment Thomas saw on display at a scientific seminar in 1976. The display created the illusion that a light bulb remained lit after it had been turned off, using a system of mirrors to reflect another lit bulb. A year afterward, Thomas started working with various types of mirrors in an effort to create three-dimensional illusion effects, succeeding with a set of concave mirrors. Thomas believed that visual data presented through

THE ILLUSION TRANSMITTER

Valerie L. Thomas was inspired by a simple demonstration at a seminar she attended in the mid-1970's. The demonstration she observed used a system of mirrors to project an image of a lit light bulb. Her work experience with the National Aeronautics and Space Administration (NASA) gave her the insight to realize a version of this basic principle could become useful for other applications, including the satellite systems she had been working on for years. She quickly designed her concept, calling her invention the illusion transmitter. She applied for a patent on December 28, 1979, and received patent number 4,229,761 on October 21, 1980.

Thomas's machine goes beyond the idea of television's projection of two-dimensional pictures onto a screen. Instead, the illusion transmitter presents three-dimensional images. These projections, like holographs, can appear in varying spatial relations to a viewer, allowing them to appear to occupy the same physical location as their viewers. The image is generated through the use of a concave mirror system, which places one mirror next to the object being projected and one in the location where the projection is received. It is then transmitted electromagnetically in real time, either over the airwaves or by cable.

Though originally developed for NASA's Landsat system, the illusion transmitter has a number of potential functions. For example, it has been used by NASA for meteorological applications and crop mapping. In this project, Thomas worked with a number of other countries to predict global crop yields specifically for wheat production. Images sent from illusion transmitters on the Landsat satellites can help scientists understand the nature of astronomical phenomena, as well as of the earth itself. Another potential purpose is to simplify complicated medical procedures for surgeons.

three-dimensional models would be more precise and appealing, and she envisioned both commercial and NASA applications for the process.

Although similar to holographic imaging devices, the illusion transmitter is not strictly equal to such devices, which use coherent radiation and front-wave reconstruction methods that make them impractical for common use. The illusion transmitter provides a similar effect by using a concave mirror system. One mirror is located close to the object being projected, while another concave mirror is located at a distant location. As a result of the way the human eye perceives an object, the mirrors project three-dimensional illusions in real time. Thomas applied for a patent on December 28, 1978. It was granted almost two years later, on October 21, 1980.

After retiring from NASA, Thomas worked promoting the study of science in middle schools and high schools. She has presented papers at conferences and mentored and tutored students who are interested in mathematics and the sciences. She has also created a way to improve problem-solving performance for mathematics students, as well as a professional development model for implementing her program.

IMPACT

The illusion transmitter has a variety of both current and potential applications. It has been used by NASA and other groups to make crop predictions, to track weather patterns in relation to agricultural applications, and to transmit three-dimensional images from space. The ability to view spatial bodies in accurate, real-time images allows scientists to better understand their nature. The device may also save lives, as researchers are investigating its potential application in surgical procedures.

Thomas's work with NASA and other governmental agencies, her advances in scientific and analytical thought processes, and her body of achievements have made her a strong role model for young people everywhere. In an effort further to encourage interest in science and mathematics, she has worked with young people through the NTA and Science Mathematics Aerospace Research and Technology (SMART). She has also visited educational institutions from elementary schools through colleges, mentored student workers at the GSFC, judged science fair entries, and worked with Women in Science and Engineering (WISE). Her successes have opened doors for African Americans and women in many realms.

—*Theresa L. Stowell*

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See also: George R. Carruthers; Ivan A. Getting.

BENJAMIN THOMPSON

American physicist

Thompson's scientific studies greatly advanced understanding of heat and heat transfer. He invented the slow-roasting oven, improved oil lamps, improved double boilers and drip coffee makers, and the modern fireplace with a smoke shelf to prevent downdrafts.

Born: March 26, 1753; Woburn, Massachusetts
Died: August 21, 1814; Auteuil, France
Also known as: Count Rumford
Primary fields: Household products; physics
Primary inventions: Rumford stove; slow-roasting oven

EARLY LIFE

Benjamin Thompson was born to Benjamin Thompson, senior, and Ruth Simonds on March 26, 1753, in the town of Woburn, Massachusetts. His father, a farmer about whom little is known, died in November, 1754. His mother married again in March of 1756 to Josiah Pierce, Jr. Late in life, Thompson recalled his stepfather as a tyrant who virtually forced the child from the home, but this is not borne out by the historical evidence.

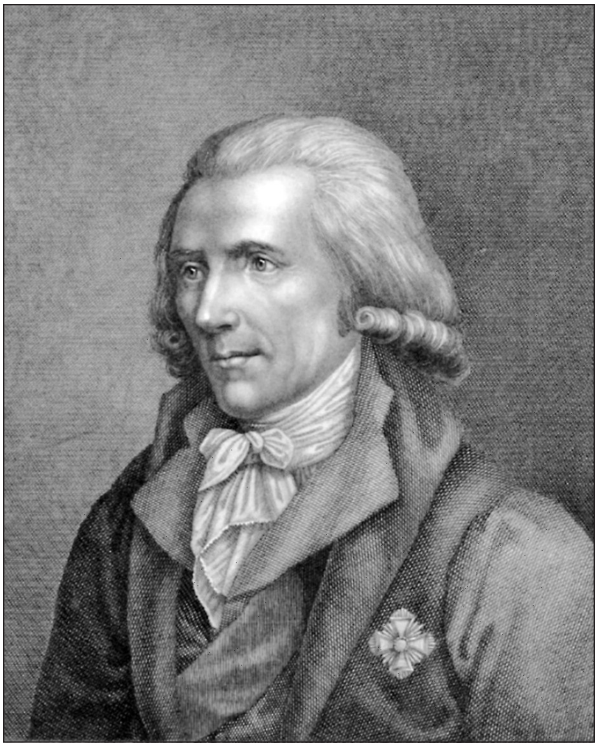
Schooling was hard to come by in colonial Massachusetts, but the young Thompson managed to attend three schools before the age of thirteen. Showing himself to be a bright boy deeply antagonistic to farmwork, he ended up an indentured apprentice to John Appleton, a successful retail merchant in the nearby town of Salem, in October, 1766. He continued his education on an informal, individual basis under the guidance of the Reverend Thomas Barnard, the Salem schoolmaster, with an emphasis on mathematics and astronomy.

Thompson's apprenticeship under Appleton ended dramatically when Thompson injured himself in an explosion while attempting to manufacture homemade fireworks. His injuries were so severe that he was sent home to Woburn to be cared for by his mother. In October, 1769, as soon as his injuries permitted, he returned to work in the employment of Hopestill Capen, the owner of a dry goods shop in Boston. Thompson continued to educate himself through self-study and experimentation to the extent that Capen fired him for neglecting his duties in the shop. He returned to Woburn in 1770 and supported himself cutting firewood.

While back in Woburn, Thompson befriended Loammi Baldwin, one of the leading engineers in the colony. Baldwin and Thompson remained in correspondence for the rest of Thompson's life, with Baldwin carefully preserving Thompson's letters. Thompson boarded with and studied medicine under the town physician, paying his way by teaching in the nearby towns of Wilmington and Bradford. The schoolmaster in Bradford helped Thompson obtain a position as schoolmaster in Concord, New Hampshire. He took up his duties there in the summer of 1772 at the age of nineteen.

LIFE'S WORK

Thompson's career as an inventor and scientist was secondary to, but an integral part of, his primary career as a social climber. He began by marrying Sarah Walker Rolfe, the widow of Colonel John Rolfe, a wealthy and prominent New Hampshire politician. Thompson was nineteen; she was thirty-three. Thompson and his bride dined on their wedding day with John Wentworth, the royal governor of the colony of New Hampshire, and Thompson quickly forged a bond with him. Wentworth was interested in science and technology and possessed one of the finest libraries in the American colonies.



Benjamin Thompson.

THE RUMFORD STOVE

The standard fireplace in 1795 consisted of a rectangular box recessed into the wall and opening directly into a full-throated chimney above it. The fire was built at the rear of the box. Hot air generated by the flames rose vertically upward, exiting the room without heating it. The room and its occupants were warmed only by radiant heat received directly from the flames, supplemented by whatever radiation reflected from the rear wall of the fireplace. Winds blowing across the chimney frequently forced smoke back into the room. The fireplace was dirty, smelly, ineffective, and expensive to fuel.

The Thompson fireplace (known at the time as the Rumford stove) was an elegant and economical improvement over the standard fireplace. Installation consisted of building a new firebox within the old so that existing homes could be retrofitted without tearing out the old firebox and chimney.

The new firebox had a rear wall built at the center of the old firebox. This brought the fire closer to the front of the hearth, where it could illuminate more of the room with its radiant heat. The rear wall was shorter than before, with the sides angled in to meet it obliquely. The footprint of the fireplace became a truncated triangle rather than a rectangle. The sides of the firebox no longer radiated uselessly toward each other, but out into the room.

This design narrowed the exhaust flue just over the fire. The hot gases then accelerated to high speed as they flowed through the narrow throat. This created a strong draft that kept the fire burning vigorously. The extra masonry needed support from behind; support bricks formed a shelf (the “smoke shelf”) that deflected cold air attempting to infiltrate the firebox via the chimney. The increased efficiency was enough to permit a smaller fire to adequately heat the room, justifying the smaller firebox.

Kitchen fireplaces of that era had a separate brick box built in for baking. This chamber was preheated with a fire built directly into it. As soon as the brick interior was hot enough, the coals and ashes were swept out and the food inserted. Radiant heat from the hot bricks baked or roasted the food without tainting it with taste and smell of smoke.

Thompson’s oven (not to be confused with his stove) replaced this brick chamber with an iron box in direct contact with the flue gases of the main fire. The iron box, with its high thermal conductivity, would quickly heat to the required temperature, bake or roast the food inside by radiant heat, and prevent smoke contamination. All of this was accomplished with less fuel and more convenience than the brick oven approach.

These inventions and others—including the slow-roasting oven, the double boiler, and the drip coffeemaker—after further improvements, still contribute to modern daily comfort. The modern fireplace is little changed from Thompson’s original design.

Thompson had ready access to the governor’s books and instruments, all of which he studied assiduously.

Thompson’s climb to prominence and wealth began against the backdrop of the American Revolution. He acquired a commission as major in the Fifteenth Regiment of the New Hampshire Militia with duties of organization and recruitment. He proved to be naturally adept at both, acquiring skills there that would serve him well for many years. Thompson was particularly skilled at identifying and repatriating deserters from the British forces occupying Boston under General Thomas Gage. When this work became public knowledge in New Hampshire, Thompson became persona non grata in Concord and had to leave town precipitously. He fled to Boston to join General Gage’s staff, abandoning his wife and newborn daughter.

Over the next twenty-four years, Thompson served as a spy for the British army in revolutionary New England; aide to secretary of state for the colonies during the revolution, Lord George Germain; undersecretary of state for the colonies; commandant of the King’s American Dragoons, raised and based in South Carolina (retiring with the rank of colonel); and aide-de-camp to Carl Theodor, elector of Bavaria. Theodor eventually ennobled Thompson as Count Rumford. Along the way, Thompson raised and spent several fortunes, never hesitating to use his offices to enrich himself.

Thompson’s duties for the Bavarian military began with reform of the army but expanded into the establishment of prison workhouses to produce military materiel, and poorhouses to house Bavaria’s impoverished. Feeding all of these people in the cheapest, most efficient way possible inspired Thompson to improve the design and operation of institutional kitchens. His improved kitchen stove used many small fires with enclosed flames to keep the hot gases in contact with the cooking pans. The flue gases were used to cook additional foods before escaping up the chimney. During this time, he invented the first slow-roasting oven, a product that proved immensely popular throughout Europe and America.

While supervising the manufacture of cannons for the Bavarian army, Thompson observed that the production of heat while boring the cannons appeared to be inexhaustible. Inspired to perform detailed experiments, he showed that the heat produced was directly proportional to the length of the boring process and was quantitatively the same whether the bore was or was not cutting metal. These results were incompatible with the caloric theory of heat, which regarded heat as a material substance released from matter when it is cut, compressed, or otherwise stressed. Thompson explained the heat as a product of the work done in mechanical processes. His interpretation was later incorporated in the theory of heat as random molecular motion, and his results validated by James Prescott Joule's measurements of the mechanical equivalent of heat.

Thompson returned to London in October, 1795, hoping to publish his scientific papers and reingratiate himself with British society. Finding this difficult to do, Thompson threw himself into developing and marketing his kitchen stoves, roasters, and fireplaces. Appalled at the dirty and inefficient fireplaces prevalent in England, he set about to improve them. Thompson's new improved fireplaces were soon in much demand in England, Scotland, and Ireland and made him (once again) a wealthy man.

Thompson left England in September, 1802, to settle his affairs in Bavaria. On the way back to England, he passed through Paris, where he was seduced by the ladies of Parisian society and Napoleon Bonaparte, emperor of France. He consummated an ultimately unhappy marriage to the wealthy and socially prominent widow of Antoine Lavoisier, the founder of chemistry. During this period, he invented improved oil lamps and improved drip coffeemakers and experimented with new soapmaking techniques. He remained in France until his death in Auteuil on August 21, 1814.

IMPACT

Thompson's innovations increased the efficiency and economy of heating, cooking, and lighting at a time when the cost of fuel was a large part of domestic expense. Thompson lived during the Industrial Revolution, when the business consumption of energy began to compete with and place economic pressure on domestic consumption. When wood became scarce, it was replaced by coal. However, much like the present day, continued expansion of the industrial economy without a corresponding decrease in standards of living demanded the energy available be used with the greatest possible efficiency. Households that adopted Thompson's improved fireplaces and ovens profited immediately from a significant drop in heating and cooking costs while also enjoying a warmer, cleaner home. Air pollution and the cost of fuel were both less than what they otherwise would have been.

Thompson is better known today as a scientist than as an inventor, remembered for his measurements of the amount of heat produced by mechanical action. His hypothesis that the heat produced is traceable to the work done during the boring process has proved to be correct. The new perspective these seminal experiments opened on the theory of heat eventually led to the recognition of heat as a form of energy, a fact not fully understood until the formulation of the law of conservation of energy and the development of the atomic theory of matter.

—Billy R. Smith, Jr.

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See also: Nils Gustaf Dalén; Sir Humphry Davy; Sir James Dewar; Benjamin Franklin.

JOHN T. THOMPSON

American army officer and businessman

Thompson, in collaboration with Theodore Eickhoff and Oscar Payne, conceived the American version of the submachine gun.

Born: December 31, 1860; Newport, Kentucky
Died: June 21, 1940; Great Neck, Long Island, New York
Also known as: John Taliaferro Thompson (full name)
Primary field: Military technology and weaponry
Primary invention: Thompson submachine gun

EARLY LIFE

John Taliaferro Thompson was born December 31, 1860, to Lieutenant Colonel James Thompson and Julia Maria Taliaferro. John had one older sister, Frances. James Thompson graduated from West Point in 1851 and was a distinguished artillery officer during the Civil War, but in 1869 he left the Army and began an academic career teaching military science at Indiana University. By age sixteen, John Thompson had decided to pursue a military career. He graduated from West Point in 1882, eleventh in his class. That same year, he married Juliet Estelle Hagans. Within a year their son, Marcellus Hagans Thompson, was born. Like his father and grandfather, Marcellus would graduate from West Point and enter the Army. Upon commissioning, John entered the Army artillery, and between 1882 and 1889 he was trained in engineering and artillery. In 1890, he transferred to the U.S. Army Ordnance Department.

LIFE'S WORK

In 1898, Thompson was promoted to lieutenant colonel and appointed chief ordnance officer for the U.S. Expeditionary Forces in the Spanish-American War. While chief ordnance officer, he recognized that the Army's small arms were obsolete and that there was a need for standardized weaponry and a need to increase the firepower of the individual soldier. This realization prompted his search for an efficient, rapid-fire personal small arm.

Thompson was appointed chief of the Small Arms Division of the Army Ordnance Department in 1907. In this capacity, he supervised development of the highly successful M1903 Springfield rifle. While with the Ordnance Department, Thompson carried out extensive tests on rifle and pistol cartridges, resulting in the U.S. armed forces adopting the standardized .30-caliber rifle cartridge and .45-caliber pistol cartridge, which remained service standards through the 1950's. Thompson was also an advocate of the Gatling gun as an infantry weapon because of its ability to concentrate firepower.

Because of his insistence on the need for sustained firepower and automatic weaponry, Thompson was considered a radical thinker within the Army, which at the start of the twentieth century was still dominated by aging nineteenth century cavalry commanders. Traditional military tacticians emphasized numerical superiority, whereas Thompson believed that firepower was a practical substitute for manpower. Because it was peacetime, the Army felt no need to pursue development of automatic weapons, though European nations were actively purchasing machine guns, automatic rifles, and semiautomatic pistols designed by Hiram Percy Maxim, John Moses Browning, Isaac Newton Lewis, Hugo Borchardt, Benjamin Hotchkiss, Georg Luger, and the German arms manufacturer Mauser. Thompson became frustrated with the Army, feeling that his military career was not allowing him the chance to design similar automatic weapons. In 1914, Thompson retired from the Army to become a consultant to the Remington Arms Corporation.

While the Remington job was interesting and challenging, Thompson used his evenings to design a simple, dependable, self-operating breech mechanism for an automatic weapon. In 1915, he contacted John Bell Blish, a retired naval officer who had designed and patented a blowback breech self-actuating mechanism. Thompson decided to design an automatic weapon around this delayed blowback system. In 1916, he founded the Auto-Ordnance Corporation, backed by money from Thomas Fortune Ryan, a supporter of the Irish Republican Army (IRA). Thompson, along with engineers Theodore Eickhoff and Oscar Payne, worked to develop a handheld automatic weapon during the course of World War I.

Thompson recognized the need for a handheld machine gun that could lay down sustained fire as a soldier advanced across open terrain or for use to clear enemy trenches. In 1917, as the United States entered the war, Thompson was recalled to active military duty and appointed director of arsenals. In 1918, he was promoted to brigadier general. Production of the first Auto-Ordnance automatic guns, nicknamed the "Persuader" and "Annihilator," arrived too late to be used in action during the war: The first shipments were dock-bound when the Armistice was signed. In 1919, Thompson was awarded the Distinguished Service Medal for his meritorious service

THE THOMPSON SUBMACHINE GUN

The Thompson gun was designed as a sub-caliber machine gun, firing pistol-caliber ammunition rather than rifle-caliber ammunition of previous machine guns. A one-man, handheld weapon with a high rate of fire for close-in fighting, the Thompson gun was especially effective for clearing enemy troops from entrenched positions. The gun was known as the "Tommy gun," "trench broom," "chopper," "Irish sword," and "Chicago piano."

The Thompson submachine gun was designed to provide World War I soldiers with increased individual firepower. The first shipment of war-bound guns for American forces in Europe arrived at the New York docks on November 11, 1918, the day of the Armistice. The Thompson gun was then modified for nonmilitary use, and in 1921 the M1921 Thompson submachine gun entered the commercial market. Despite its high price of $200, the Thompson won approval among users. A Thompson submachine gun could be purchased by mail order or at sporting goods or hardware stores. Firing the .45 ACP (automatic Colt pistol) cartridge fed from box magazines of twenty and thirty rounds, or large-capacity fifty- and one-hundred-round drum magazines, the gun is a powerful weapon that fires fifteen hundred rounds per minute. A Cutts compensator at the muzzle keeps the gun under control during automatic fire. After the M1921's release, criminals and law-enforcement agencies took to the Thompson gun, and it was many years before the negative image associated with criminal use was overcome.

The Thompson submachine gun's basic operation is a delayed blowback (the delay initially provided by a brass Blish hesitation lock) consisting of two metal blocks sliding against each other at an oblique angle. The hesitation lock was found to be unnecessary, and later Thompson guns were produced without it. The M1921 and M1928 were the first Thompson guns to enter military service, being adopted in 1925 by the U.S. Coast Guard and Marine Corps, yet manufacture of Thompson guns did not reach substantial levels until the beginning of World War II, when France and Great Britain needed reliable small arms with high rates of fire. The Thompson M1928 is perhaps the most well known of the Thompson submachine gun models, though it actually differs little from the M1921, apart from having a reduced rate of fire (seven hundred rounds per minute) and some versions having different forearm furniture. Unfortunately, the M1928 required labor-intensive production processes involving many machined parts. The M1928 gave excellent service to many Allied troops and also continued to be a favorite weapon among criminal organizations for its small size and ease of disassembly for concealed carrying.

The Thompson M1 was the M1928 redesigned for wartime mass production by the Savage Arms Company. The M1 went into production in 1942 using a simplified blowback design and removed the M1928's compensator and barrel-cooling fins. The M1 went into widespread use by U.S. military forces but was eventually superseded by the M1A1, which had a set firing pin configuration rather than hammer type used in the M1 and M1928. The M1A1 remained in regular military and police use until the mid-1960's.

Vintage Thompson guns are highly sought after by collectors. Currently, a semiautomatic version of the Thompson gun is manufactured by Auto-Ordnance Corporation, a division of Kahr Arms. Kahr Arms purchased Auto-Ordnance in 1999, though it was not the original Auto-Ordnance founded by John T. Thompson, which changed hands several times after World War II before being sold in 1951 to Numrich Arms Corporation.

in design and production of arms and ammunition to the U.S. Army and released from service. That same year, his son, Marcellus, resigned from the Army and became vice president and general manager of Auto-Ordnance.

During 1919, the prototype Thompson submachine gun was produced and by 1920 was undergoing testing by the U.S. government. Test results were impressive, but no service recommended adopting the weapon. Auto-Ordnance realized that it was difficult to market submachine guns during peacetime, so the company began an extensive advertising campaign using the mottos "The most effective portable fire arm in existence" and "On the side of law and order." This marketing strategy resulted in mixed sales of the Colt-made M1921 Thompson submachine gun: While there were steady sales to law enforcement, many guns found their way into the hands of criminals, and a number of Thompson guns were smuggled into Ireland and used by revolutionaries against British forces.

The Thompson gun faced several additional peacetime marketing problems: The gun sold for around $200, at a time when postwar surplus machine guns sold for about $10. Also, the Thompson fired the .45 ACP (automatic Colt pistol), a pistol cartridge deemed obsolete as early as 1911 and used by no other military powers but the United States. During the 1920's, the gun was readily available to Prohibition Era gangsters, Irish rebels, anti-union mine owners, strikebreakers, and enforcers. By the economically depressed 1930's, the reputation of the Thompson gun's image was mythically linked to professional criminals and gunmen. By the late 1930's, Europe verged on war, and orders for the M1928 started to arrive from Great Britain and France. However, Colt refused to manufacture the M1928 because of its perceived criminal reputation. As a result, Auto-Ordnance signed a contract with Savage Arms Company to produce the first truly military Thompson submachine guns. Savage made its first delivery in April, 1940, and by late 1940 the war in Europe was fully engaged. Britain, France, and Russia ordered hundreds of thousands of Thompson guns.

For nearly twenty years, Thompson and his investors had been distressed and plagued by their submachine gun's scandalous reputation. On June 21, 1940, Thompson died; he would never see his invention help free the world from the terrors of World War II. Throughout the war, the Thompson submachine gun went through several redesigns to simplify manufacture, lower cost, and adapt it to combat conditions. The Thompson gun proved a solid, reliable weapon especially suited for European and Pacific battlefields: Though it was heavy and sand could clog it, the gun had excellent stopping power, one soldier could lay down immense firepower, and its distinct firing sound intimidated the enemy. The "Tommy gun" became a favorite of elite fighting forces such as rangers, paratroopers, and special operations groups, and it was issued in great numbers to infantry and armored groups. Numerous wartime stories relay how the Thompson gun's single-handed firepower saved the day.

IMPACT

Military historians credit Thompson with modernizing American infantry ordnance from 1900 through World War I. Thompson's M1921 gun is the first weapon deemed a "submachine gun," a term Thompson coined. The Thompson gun is considered to have one of the most distinct and recognizable designs in firearms history. The use of Thompson guns, and other automatic weapons such as the Browning automatic rifle (BAR), by criminals resulted in the National Firearms Act of 1934, which aimed to keep such weapons out of the hands of Depression Era bandits. During World War II, more than 1.5 million variations of Thompson submachine guns were produced. Many veterans consider it the best weapon of the war. The Thompson submachine gun remained in military and police use well into the 1960's.

—*Randall L. Milstein*

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See also: John Moses Browning; Samuel Colt; Richard Gatling; Hiram Percy Maxim.

ELIHU THOMSON

English electrical engineer

Inventor and entrepreneur Thomson was prominent in the field of electrical engineering because of his creation and skillful marketing of early electric light and power systems in the United States, the United Kingdom, and France.

Born: March 29, 1853; Manchester, England
Died: March 13, 1937; Swampscott, Massachusetts
Primary field: Electronics and electrical engineering
Primary inventions: Improved X-ray tubes; recording watt meter

EARLY LIFE

Elihu Thomson (ee-LI-hew TOM-suhn), the second of seven children born to Daniel Thomson and Mary Ann Rhodes, was born in Manchester, England, on March 29, 1853. Elihu's father was a mechanic specializing in the installation of factory machinery, but he had difficulty finding steady work in England. In 1858, Daniel immigrated with his family to the United States and settled in Philadelphia, taking a position with the Southwark Foundry owned by Merrick and Sons. His work entailed a great deal of travel, often to such distant places as Cuba, so the running of the household and Elihu's upbringing were mostly the responsibility of Elihu's mother. One of her favorite pastimes happened to be stargazing, and she demonstrated the patterns of constellations and stars to her son, sparking his lifelong love for astronomy.

Thomson began his education in a local Philadelphia elementary school, where he met his first mentor, teacher George Stuart, and began to take an interest in mathematics and engineering. Thomson's genius for invention and his quick-wittedness were remarked on by his instructors and his peers, leading to the early completion of his grammar school studies. At age eleven, Thomson passed the entrance exams for Philadelphia's premier public school, Central High School. Unfortunately, he could not matriculate until he was thirteen years old, so Stuart unsuccessfully tried to persuade the boy to take more interest in his physical development than in additional education for a few years. Distressed by the idea of several years without books, Thomson persuaded his parents to allow him to direct his own studies, involving, especially, the reading of his father's copies of *The Imperial Journal of Art, Science, Mechanics and Engineering*, published in Manchester in 1840 and 1841, which impressed upon the young Thomson the importance of inductive reasoning in scientific studies. He read and reread the articles, inspired by them to conduct early experiments on his own, one of which involved creating a crude electrostatic device from a wine bottle.

At Central High School, Thomson was such a talented student that, after graduating, he was appointed assistant professor of chemistry and mechanics at the Franklin Institute, spending more of his time building optical lenses and electrical motors than teaching classes and delivering lectures. In 1876, at twenty-three, he was promoted to chair of chemistry. Teaching, however, was not the career that fueled Thomson's imagination. In 1880, having become nearly obsessed with possible applications for electricity, Thomson resigned as chair in order to pursue electrical research full time.

LIFE'S WORK

The three-coil dynamo was one of Thomson's earliest inventions; along with an automatic regulator, the coil was

Elihu Thomson. (The Granger Collection, New York) the basis of his electric lighting system. In 1880, he and fellow science professor Edwin Houston established the Thomson-Houston Electric Company for the purpose of profitably manufacturing and selling arc lamp systems. When the company proved to be financially successful, Houston and Thomson bought into other electrical markets, which led to the founding in 1880 of the American Electric Company in New Britain, Connecticut. The purchase of the Sawyer-Man Electric Company in 1886 enabled them to begin the manufacture of incandescent lamps. In 1892, having sufficient capital, Thomson-Houston merged with former competitor Edison General Electric Company to become the General Electric Company. In 1893, a Parisian office of Thomson-Houston was opened and named the Compagnie Française Thomson-Houston (CFTH). From this company derived the modern Thomson SA Company, which still manufactures televisions and other multimedia devices.

In 1896, Elihu Thomson built electrical equipment for the production of X rays, improved X-ray tubes by designing one that used cathode rays to produce more intense radiation than had been previously possible, and was one of the earliest proponents of stereoscopic "Röntgen pictures" as a investigative tool for the diagnosis of bone fractures and to aid in the medical removal of foreign objects. However, despite his work in improving the field of X-ray technology, he was also one of the few working in the field of radiation who admitted the dangerous effects of overexposure to radiation. At a time when X-ray demonstrations were held at cocktail parties, Thomson wished caution to be observed by all technicians. To prove his point, in November of that year, Thomson intentionally allowed a finger on his left hand to be burned by overexposure to radiation. Merely one-half hour of exposure per day was enough to cause observable pain, swelling, stiffness, and blistering of the skin.

THE RECORDING WATT METER

For much of Elihu Thomson's career and in many of his most famous patents, Thomson refined the existing technology created by other inventors as often as, if not more often than, he would create technology based on new principles. For example, during the 1880's, Thomson took competitor Thomas Alva Edison's design for a motor meter, improved on it, and created an early version of his "recording wattmeter"—an invention that proved very popular because of its ease of use and rugged design.

Between 1878 and 1888, Edison had invented an electricity meter that used the principle of electroplating to measure an amount of electricity instead of merely recording an electrical current's duration. In Edison's "chemical meter," copper plates were suspended in jars containing copper sulphate, and the whole jar was exposed to an electrical current. The electricity would cause a chemical reaction to occur in the jars, dissolving the zinc. Once the current ceased, a person "read" the amount of electricity used by removing the copper plates from the jars and weighing them. Even though the system was clumsy and difficult to use (on more than one occasion, an assistant's mishandling of the plates caused errors in measurement and, consequently, overbilled customers), Edison preferred it to later experiments he tried involving a meter run by an electric motor because he found chemistry experiments more personally satisfying. Consequently, Thomson observed an opportunity to design what he thought might be a more effective system for measuring electric output.

Thomson's meter operated using both alternating and direct current and was less often affected by user error and inaccuracy than Edison's chemical meter. A heating element was connected into Thomson's meter's circuit and warmed the lower of two alcohol-filled bottles. The alcohol in the bottle would slowly evaporate as it heated and floated into the other bottle above it. With the shifting of weight, the top bottle would drop down like a pendulum closer to the thermal unit and move the now-lighter bottle into cooler air. This rocking motion would cause the register to tabulate the energy used, moving slowly and smoothly enough that friction between the gears would not cause the meter to mistake gear friction for energy usage.

In addition to his social awareness of the dangers of X rays and their responsible use, Thomas demonstrated through his inventions his care for the health of the average worker (perhaps inspired by his working-class ancestors) and was particularly interesting in improving working conditions. He espoused the use of helium rather than nitrogen in the breathing mixture used by divers and tunnel workers to prevent "the bends," also known as caisson disease. Further, the inert nature of helium, he theorized, could extend the depth to which divers could proceed underwater.

Besides X-ray technology and the creation of electric coils, Thomson was also interested in improving technology once used by his father. Before 1887, a mechanic could only weld two pieces of metal together by heating one or both in a fire—a technique that had evolved out of ancient metalworking practices and had not seen much refinement since. High melting points and two metals with radically different melting points made forging in the traditional way impossible. Thomson's solution, to insert two materials to be welded in a parallel circuit and run an electric current through them, was an elegant way to overcome this problem. The creation of this process allowed Thomson Electric Welding, a second Thomson-founded company, to advance the construction of new appliances and vehicles in society. The electric air drill, still used in industry today, is but one of the many practical and useful discoveries for which Thomson became not only wealthy but also renowned.

Having achieved a certain financial stability for his family, Thomson finally turned his attention back to education and attended first Yale University and then Tufts College (where he received his Ph.D.). Thomson's Ph.D., however, was one of several degrees he received from many other prestigious universities around the world. He was, for many years, a professor of electrical engineering at the Massachusetts Institute of Technology (MIT) and even an interim president (twice, between 1920 and 1923) for the university.

Thomson's personal life, however, was more difficult than his professional one: his first wife, Mary Louise Peck, whom he had married in 1884 and with whom he had four children (Stuart, Roland Davis, Malcolm, and Donald Thurston), died in 1916. It was only in 1923 that he married again, to Clarissa Hovey, whom he described as the ideal assistant and supporter in his research. Thomson died in his bed at his estate in Swampscott, Massachusetts, on March 13, 1937, at the age of eighty-four. He was buried in the Pine Grove Cemetery in Lynn, Massachusetts.

IMPACT

Thomson's studiousness and determination led to a prolific career as an inventor. His nearly seven hundred patents (a wide variety of inventions and refinements involving dynamos, three-phase generators, repulsion-induction motors, electric welding, transformers, meters, lamps, railways, and steam engines) made him the third most prolific inventor in history. Thomson was educated in engineering, mechanics, and chemistry, and he used a combination of these disciplines (some learned at his father's knee) to power the creative imagination that spawned so many new inventions. His work demonstrates clearly how a thorough understanding of a mechanical skill can lead to the creation of new processes and new products. Further, his financial success and the continued existence of many of the companies founded by him demonstrate the value of practical thinking and skillful marketing techniques. At General Electric, it was Thomson's skill as a marketer as well as his creativity as an inventor that allowed profitable products to become a realistic outcome of creative thought. Unlike his contemporary Nikola Tesla, who was perhaps more creative as an inventor but died in poverty, Thomson was also a shrewd businessman who left a legacy behind after his death.

—*Julia M. Meyers*

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See also: Thomas Alva Edison; Wilhelm Conrad Röntgen; Nikola Tesla.

MAX TISHLER

American chemist

Tishler led research teams that synthesized ascorbic acid (vitamin C), cortisone, riboflavin, pyridoxin, pantothenic acid, nicotinamide, methionine, threonine, and tryptophan. He led a microbiological group that developed fermentation processes for actinomycin D, vitamin B_{12}, penicillin, and streptomycin. He also invented sulfaquinoxaline to treat coccidiosis.

Born: October 30, 1906; Boston, Massachusetts
Died: March 18, 1989; Middletown, Connecticut
Primary field: Chemistry
Primary inventions: Synthetic vitamins; sulfaquinoxaline

EARLY LIFE

Max Tishler was born in Boston, Massachusetts, the fifth of six children of Samuel and Anna Tishler, Jewish immigrants from Romania and Germany, respectively. Samuel abandoned the family when Max was four or five years old, and from an early age everyone had to work. Max and his younger sister were the only ones to graduate from high school, and he was the only one to attend college. Max worked in a drugstore until he completed graduate school (Boston English High School) and earned enough to support himself, pay his tuition, and help his mother and younger sister.

Tishler attended Tufts College (now Tufts University) with a $400 annual fellowship and, during his senior year, with a teaching assistantship. First an English major, he later became a chemistry major. Although one professor advised him not to do so because of prejudice against Jewish chemists, another encouraged him to enter the field to help break down the current barriers. In 1928, he received his B.S. degree in chemistry and became a licensed pharmacist.

Beginning in 1930, Tishler attended Harvard University with a $1,000 annual teaching assistantship. He received his M.A. and Ph.D. degrees in 1933 and 1934, respectively. On June 17, 1934, he married Elizabeth M. Verveer, who had been a student in his freshman chemistry laboratory at Tufts. The couple had two sons, Peter Verveer Tishler (b. 1937), a physician and genetics researcher, and Carl Lewis Tishler (b. 1947), a clinical psychologist.

Tishler stayed at Harvard as research associate (1934-1937) and instructor (1936-1937). Since no academic position was available, in 1937 he became a research chemist at Merck and Company in Rahway, New Jersey, then known only as a producer of reagent chemicals, where he was put in charge of developmental research.

LIFE'S WORK

In the late 1930's, George Merck, Jr., the president of Merck and Company, decided that, because no other American firm was working on vitamin research, his company should enter the field. Tishler's first assignment, the first of his numerous successes, was to develop a synthesis of riboflavin (vitamin B_2) different from that already patented in 1934. He simplified the procedure and increased the yield. His large-scale, economical method permitted riboflavin to be used to enrich white bread.

Tishler's next task, a new synthesis for the sulfa drug sulfapyrazine, which the cheaper penicillin had rendered uneconomical, resulted in an important spin-off. Sulfaquinoxaline, which Tishler discovered with John Weijlard in 1942, was added to chicken feed and dramatically reduced the incidence of coccidiosis (a parasitic disease of the intestinal tract caused by microscopic organisms called coccidia), which had previously killed as much as half of the flocks. Its application not only made available disease-free, nutritious, cheap food but also encouraged the search for new drugs for the poultry industry.

Although Lewis H. Sarrett had synthesized the anti-inflammatory, steroidal hormone cortisone in 1948, the yield was very low. Tishler and his team reduced the number of steps required from forty to twenty-six and greatly increased the yield. According to Sarrett, Tishler "transformed complicated organic synthesis from an esoteric intellectual exercise in the laboratory to useful products of great public value. . . . He created the paradigm of pharmaceutical research and development which has been followed by his successors throughout the industry ever since."

Tishler's research on cortisone, hydrocortisone, and dihydrostreptomycin brought him Merck's Board of Directors' Scientific Award in 1951. In what Tishler himself called "a golden age as far as medicinal chemistry is concerned," his teams developed commercial syntheses for pantothenic acid (vitamin B_3), biocytin vitamins, alpha-tocopherol (vitamin E), indomethacin (a nonsteroidal, anti-inflammatory drug), nicotinic acid (niacin), chlorothiazide, amitriptylene, aminopyrazine, aminoquinoxaline, alpha-methyldopa, and the amino acids threonine and tryptophan. His team with Robert Denkewalter and Ralph Hirschmann developed the first total synthesis of the enzyme ribonuclease. His work with Selman A. Waksman on the antibiotic streptomycin helped empty sanatoriums of patients suffering from tuberculosis, and he collaborated with Louis F. Fieser of Harvard University on a large-scale synthesis of phylloquinone (vitamin K) and a study of its relationship between its structure and biological activity.

Tishler met once a week with each of his research teams to discuss their progress. He was the author of more than 130 articles and the holder of more than one hundred patents on chemicals, vitamins, drugs, and hormones. To quote Sarrett again, "He taught me how to be human, to get a lot out of people by being warm with them. . . . I learned more from Max Tishler about research in the pharmaceutical industry than from any other man." According to Tishler's wife, "Max's vocation and avocation was chemistry."

Tishler advanced through the Merck hierarchy rapidly. From research chemist (1937-1941) he became section head in charge of process development (1941-1944), director of development research (1944-1953), vice president and executive director of scientific activities (1954-1956), president of Merck, Sharpe, and Dohme Research Laboratories (1956-1969), member of the board of directors (1962-1970), and senior vice president of research and development (1969-1970).

As he approached his mandatory retirement age of sixty-five, Tishler was asked to become head of the Weizmann Institute in Rehovot, Israel, but he declined the offer. He soon received offers from no less than nine universities. In 1970, he began his second career by joining the faculty of Middletown, Connecticut, which had recently begun its graduate program in chemistry. He continued his research on biologically active compounds with his students until a few weeks before his death. He served as professor of chemistry (1970-1974), university professor of the sciences (1972-1974), chairman of the Department of Chemistry (1973-1974), and from 1975 until 1989 as professor of chemistry emeritus and university professor of the sciences emeritus.

A lifelong smoker, Tishler ceased smoking in the hope that this would relieve his emphysema. This unpretentious and friendly scientist who had spent his whole life using chemistry to fight various diseases and who had served as mentor and role model to generations of both industrial and academic chemists succumbed to this disease at the age of eighty-two.

SYNTHESIZING VITAMINS

Max Tishler's first assignment at Merck was one of the two inventions cited for his induction into the National Inventors Hall of Fame (1982). He was asked to develop a practical synthesis for riboflavin (vitamin B_2) that was different from the methods that had been patented in 1934 by Nobel laureate in chemistry (1937) Paul Karrer—for Hoffmann-La Roche—and by Nobel laureate in chemistry (1938) Richard Kuhn—for I. G. Farben. With a catalyst, Tishler reduced an *o*-aminoazo compound that contained a ribose nucleus and reacted it with barbituric acid (a white, odorless, crystalline acid, CHON, used in the manufacture of sedatives and hypnotics, in making dyes, and as a polymerization catalyst) instead of the more expensive alloxan that Karrer and Kuhn used. His simplified procedure with increased yield ("Alloxazines and Isoalloxazines and Processes for their Production," U.S. Patent number 2,261,608, November 4, 1941) reduced the price of riboflavin from $17,479 per kilogram to less than $100 per kilogram in 1947. His large-scale, economical method allowed riboflavin, which is easily destroyed in the production of bread and milk, to be used for the first time to enrich white bread.

Tishler's next task resulted in the second invention cited for his induction into the National Inventors Hall of Fame. He was asked to develop a new, cheaper synthesis for sulfapyrazine, a sulfa drug that demonstrated possible medical applications but which was more expensive than the cheaper and better-known antibiotic penicillin. In 1942, together with John Weijlard, Tishler prepared a new sulfa drug, sulfaquinoxaline ("2-Sulphanilamido-quinoxaline Vitamins," U.S. Patent number 2,404,199, July 16, 1946), which was found to be effective against malaria in monkeys but which caused kidney stones in animal tests. Because the kidney system of fowl is different from those of monkeys and humans and because fowl are subject to coccidiosis (a disease which, like malaria, is caused by protozoa), David Green, the director of Merck's Veterinary Services, suggested that the drug be tested on them. Use of Tishler's new drug in chicken feed reduced the incidence of coccidiosis, which had hitherto killed 10 to 50 percent of the fowl, by 80 percent. His drug caused the explosive growth of broiler flocks from hundreds of thousands to billions of chickens; made available disease-free, nutritious, inexpensive food; and stimulated research on a new generation of pharmaceutical agents for poultry.

IMPACT

A great believer in team research, Tishler transformed complex organic synthesis from an intellectual laboratory exercise to the production of useful products of significant value to the public. On Tishler's death, F. Roy Vagelos, Merck's chairman and chief executive officer, described him as "an example of scientific integrity, and an inspiration of research achievement, for whole generations of scientists both in industry and academia. . . . The lives of countless patients around the world were benefited by drugs resulting from his pioneering in developmental research, and the science of chemistry was enriched." In introducing Tishler at his election to the National Inventors Hall of Fame for his large-scale syntheses of riboflavin and sulfaquinoxaline, on February 6, 1982, Lewis H. Sarrett stated, "You might say Dr. Tishler invented the term 'developmental research.'"

Tishler received many awards and honors: election to the U.S. National Academy of Sciences (1953), the Chemical Industry Award (1963), the American Institute of Chemists' Chemical Pioneer Award (1968) and Gold Medal (1977), the Eli Whitney Award for Inventions (1973), and the Sloan-Kettering Institute for Cancer Research's Chester Stock Award. In the American Chemical Society, he was chairman of the Division of Organic Chemistry (1951), society president (1972), and recipient of the Priestley Medal, the society's highest award. President Ronald Reagan awarded him the National Medal of Science in 1987 as "a giant on the chemical scene these past fifty years."

—*George B. Kauffman*

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See also: Gertrude Belle Elion; Dorothy Crowfoot Hodgkin; Percy Lavon Julian; Selman Abraham Waksman.

EVANGELISTA TORRICELLI

Italian physicist and mathematician

In an attempt to solve the problem of raising water over ten meters, Torricelli decided to employ mercury, which is fourteen times as heavy as water. He succeeded, thus inventing the barometer.

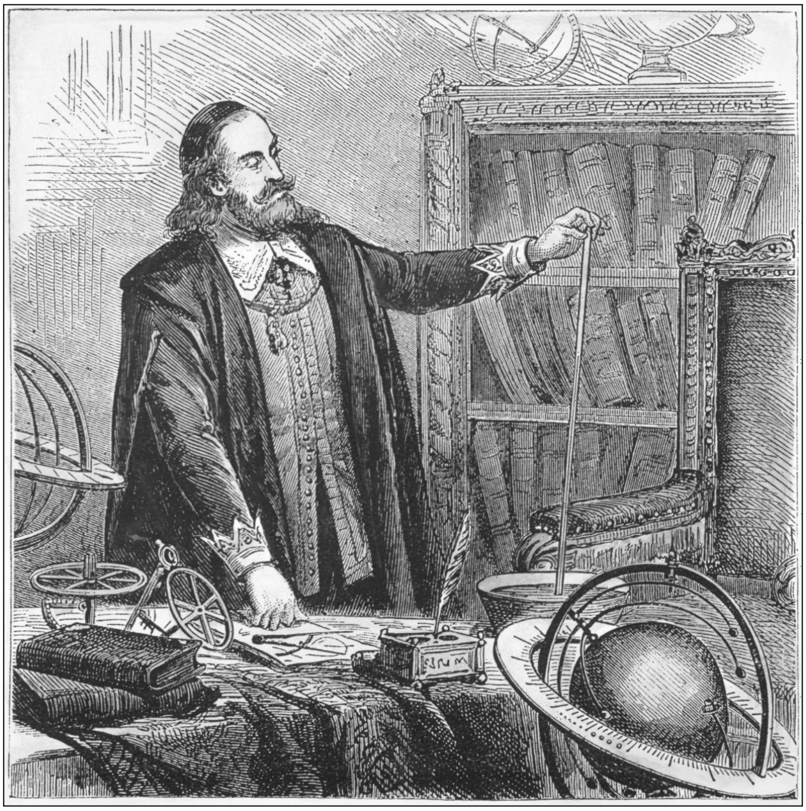
Born: October 15, 1608; Faenza, Romagna, Papal States (now in Italy)
Died: October 25, 1647; Florence, Tuscany (now in Italy)
Primary fields: Mathematics; physics
Primary invention: Barometer

EARLY LIFE

The eldest of three children, Evangelista Torricelli (eh-vahn-jeh-LEE-stah tohr-ih-CHEH-lee) was born to Gaspare Torricelli and Caterina Angetti in 1608 in Faenza, at the time part of the Papal States. Having been left fatherless at an early age, Torricelli was educated first by his paternal uncle Jacopo, a religious of the Order of the Camaldolesi, and in 1624 he entered the Jesuit College at Faenza, where he studied mathematics and philosophy until 1626. The following year, Torricelli transferred to the University of Rome to study under the

Benedictine Benedetto Castelli, an illustrious water engineer and professor of mathematics, who had also been a student of Galileo at Pisa. Among Torricelli's peers at Rome were other future well-known physicists and mathematicians such as Alfonso Borelli, Bonaventura Cavalieri, and Michelangelo Ricci. After completing his studies, Torricelli became Castelli's secretary and held this post between 1626 and 1632.

Little is known of Torricelli's activities in the period 1632 to 1641. During these years, he appears to have been secretary to Monsignor Giovanni Ciampolli, a friend of Galileo, who served as governor of a number of cities in Umbria and the Marches. Torricelli also stood in for Castelli at Rome and lectured at the university during the academic year 1640-1641. Part of the correspondence dating to Torricelli's early life has been preserved, most notably a letter of September 11, 1632, to Galileo in which he described having read the latter's *Dialogo sopra i due massimi sistemi del mondo* (1632; *Dialogue Concerning the Two Chief Systems of the World*, 1661) with delight. In his letter, Torricelli acknowledged being a follower of Galileo "in profession and sect." Yet, after Galileo's trial in 1633, Torricelli decided to shift his attention from astronomy to mathematics, an area that seemed less controversial than the Copernican theory defended by Galileo.



Evangelista Torricelli with his barometer. (The Granger Collection, New York)

LIFE'S WORK

In April, 1641, Torricelli's treatise on the path of projectiles (*De motu gravium naturaliter descendentium et proiectorum*) was presented to Galileo by Castelli. Galileo, then a man of seventy-eight, was so impressed with Torricelli's work that he invited him to his house at Arcetri, near Florence. Wishing to care for his ailing mother, Torricelli accepted the invitation but was forced to delay his departure. He finally arrived at Galileo's villa on October 10, but, after Galileo's death only three months later (January 8, 1642), he was asked to succeed the great scientist as Grand Duke Ferdinando II de' Medici's mathematician and philosopher. Torricelli remained in Florence for the rest of his life, living in the ducal palace and lecturing as professor of mathematics at the local university. He was elected to the Accademia della Crusca in Florence in 1642.

Under the auspices of the grand duke, Torricelli's *Opera geometrica* (works on geometry) was published in three parts in October, 1644. As with many scientific works published at the time, it was written in Latin because this language still expressed ideas and reported events with a precision that the vernacular lacked. Torricelli's volume included his monograph on the parabolic motion of projectiles of 1631, a commentary on Archimedes, and a series of treatises on the parabola, the cycloid, and other dimensional figures. The texts received much acclaim throughout Europe and were praised for the clarity and precision with which the author discussed rather difficult concepts. Moreover, in his work, Torricelli rendered Bonaventura Cavalieri's theory of indivisibles accessible and expanded the latter's method of indivisibles to cover curved indivisibles. With these tools, he was able to show that rotating the unlimited area of a rectangular hyperbola between the *y*-axis and a fixed point on the curve resulted in a finite volume when rotated around the *y*-axis.

In his *Opera geometrica*, Torricelli also paid attention to hydraulics, showing that, aside from his theoretical work, he had practical skills too. As an example, Torricelli advised the grand duke on marsh drainage on the Chiana Valley in Tuscany. In fact, attempting to solve a practical problem with which Ferdinand's pumpmakers had been posed, he realized that, if water could be pumped upward, this was because it was exerted by the surrounding air. Instead of water, he decided to use mercury, and he created a tube filled with quicksilver and inverted over the same liquid. This led to the development of a device that he described to his friend Michelangelo Ricci in a letter of June 11, 1644. Known first as "Torricelli's tube," it was named "barometer" by the Frenchman Edme Mariotte in his *Discours de la nature de l'air* (discourse on the nature of air) of 1676. Torricelli's practical skills were also applied to ballistics and optics. He studied projectile motion, built several large lenses, and devised telescopes and simple microscopes, making substantial financial gains from his skill in lens grinding in the last period of his life. In 1644, the grand duke gave him a golden chain bearing the words *virtutis praemia* (rewards for your talent) in return for some of the scientific instruments Torricelli had designed.

In October, 1647, Torricelli contracted typhoid fever and died a few days later at the age of thirty-nine. He was buried in the church of San Lorenzo in Florence. In his will, he entrusted his unpublished manuscripts and letters to his friends Cavalieri and Ricci, who were to prepare the material for publication. However, Cavalieri died weeks after Torricelli, and Ricci failed to accomplish the task, resulting in the bulk of Torricelli's texts being published as late as 1919. Some of the lectures given at the Accademia della Crusca had, however, already been published by Tommaso Bonaventura in 1715.

THE BAROMETER

As Evangelista Torricelli informed his friend Michelangelo Ricci in June, 1644, he had long been working on certain experiments relating to vacuum. Opposing those who claimed that a vacuum did not exist, Torricelli set out to make the barometer, "an instrument which will show the changes in the atmosphere, as it is now heavier and grosser and now lighter and more subtle."

The Torricelli barometer is made by first filling a dish with mercury. Mercury is then poured into a long tube. The tube is filled almost to the top and inverted several times, taking care that no air bubbles should get into it. After the tube has been completely filled with mercury, a finger is placed over the top of the tube, and the tube is inverted and placed into the dish below the level of the mercury. When the finger is removed, the level of the mercury inside the tube drops until the pressure at the bottom of the column of mercury is equal to the pressure exerted by the surrounding air. Since no air was allowed to enter the tube, the empty space above the mercury column is a vacuum. The pressure exerted by the atmosphere can be quantified by measuring how high the mercury column rises above the level of the mercury in the dish. The pressure in this case is 731 millimeters of mercury.

Barometers are mainly used by meteorologists to measure atmospheric pressure (also known as air pressure, or barometric pressure) and to forecast weather. As an example, whereas a quick drop in pressure over a short period of time indicates that a storm is likely in five to six hours, a slow and sustained rise in pressure indicates that a long period of fine weather is approaching. The common units of measurement that barometers use are millibars (mb) or inches of mercury. Although the classic mercury barometer is still very much used, weather stations employ a digital barometer that uses electrical charges to measure air pressure. This enables them to take multiple accurate recordings of the pressure and to produce more accurate weather forecasts.

IMPACT

Torricelli's contribution to physical and mathematical sciences is outstanding. Attempting to prove wrong the old saying that "nature abhors a vacuum," to which Galileo himself had also adhered, Torricelli was the first person to create a sustained vacuum (the so-called Torricellian vacuum). He demonstrated that atmospheric pressure determines the height to which a fluid will rise in a tube inverted over the same liquid. With his experiment, he was able to discover the principle of a barometer. As proof of Torricelli's lasting impact, his method of getting a very high vacuum is still often employed.

In the field of mathematics, Torricelli devised a problem due to the French mathematician Pierre de Fermat when he determined the point in the plane of a triangle so that the sum of its distances from the vertices is as small as possible. Torricelli's correspondence to Roberval on the area and the center of gravity of the cycloid reveals his honesty and modesty. Torricelli's achievements were extolled by many of his contemporaries, in particular by René Descartes and Constantijn Huygens. Blaise Pascal described Torricelli's work on geometry as "surpassing the discoveries made by all ancient mathematicians." The asteroid 7437 Torricelli and the torr, a unit of pressure, were named in Torricelli's honor.

—*Alejandro Coroleu*

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See also: Archimedes; Galileo; Otto von Guericke; Leonardo da Vinci; Blaise Pascal.

CHARLES HARD TOWNES

American physicist

Townes invented the maser, a device that amplifies microwaves for practical applications. His work led to the development of the laser, one of the most significant inventions of the twentieth century.

Born: July 28, 1915; Greenville, South Carolina
Primary field: Physics
Primary invention: Maser

EARLY LIFE

Charles Hard Townes was the fourth of six children born to Henry Keith Townes, an attorney in Greenville, South Carolina, and Ellen Hard Townes. At an early age, Townes was interested in finding out how mechanical objects worked. He was also interested in nature, catching insects and frogs and watching the stars with his older brother.

Townes graduated from high school at the age of fifteen and attended Furman University in Greenville. Furthering his interest in natural history, he served as curator of the university's museum. He became fascinated by the logical structure of physics during his first physics course, which he took as a sophomore. He participated in a variety of college activities, including the swimming team, the newspaper, and band. In 1935, Townes graduated summa cum laude with bachelor's degrees in science and modern languages. He enrolled at Duke University, where he was awarded a master of science degree in physics in 1936. He then enrolled at the California Institute of Technology, where he received his Ph.D. in 1939. His doctoral research focused on isotope separation and nuclear spins.

LIFE'S WORK

Townes served on the technical staff at Bell Telephone Laboratories from 1939 to 1947. During World War II, he worked on the development of radar-assisted bomb sights at Bell and received several patents in radar technology. In 1948, Townes joined the physics faculty at Columbia University in New York, where he was appointed associate professor that year and full professor in 1950. His research focused on the application of microwave radiation in microwave spectroscopy, the study of interactions between microwaves and molecules. Townes worked at the Columbia Radiation Laboratory, where he was interested in producing short-wavelength microwave radiation and amplifying microwaves for use in practical applications. He served as the executive director of the laboratory from 1950 to 1952.

The Maser

An atom consists of negatively charged electrons bound to a positively charged nucleus. These electrons can occupy only certain specific energy levels, called orbitals. A photon, or light wave, that interacts with an electron in an atom has a high probability of being absorbed if its energy is exactly matched to the difference in energy between the initial orbital the electron is in and another orbital that the electron can move to. This interaction moves the electron to the higher energy level. However, once an electron has moved to a higher energy orbital, called an "excited" state, the electron will move back to a lower energy state, emitting a photon that carries away the excess energy. This process is called "spontaneous emission." Normally, spontaneous emission occurs quite rapidly, on time scales shorter than a few nanoseconds. However, some excited states are "metastable," allowing the electron to remain in these excited states for a much longer time.

If a photon having an energy corresponding to the difference in energy between the metastable state and the lower energy state interacts with an electron in a metastable state, this interaction can induce the electron to return to the stable state. This process, called "stimulated emission," results in the emission of two photons, each having an energy corresponding to the difference between the higher and lower energy states. The maser operates on the principle of stimulated emission, which was introduced by Albert Einstein in 1917.

In a collection of molecules, most of them will normally be in the lowest energy state. Charles Hard Townes had to find a way to concentrate the molecules in the excited state, something physicists call a "population inversion." He devised a technique using a nonuniform electric field, so that ammonia molecules in the excited state were repelled by the field and focused into the active chamber of his device, while molecules in the ground state were attracted by the field. Thus, many of the molecules in the chamber of his device were in the metastable excited state.

Initially, Townes added energy into a chamber filled with ammonia gas, a process called "pumping," because it causes some of the ammonia molecules to be pumped up to the excited state. The gas then went through the separator that Townes devised, concentrating the molecules that are in the excited state in the chamber. Introducing a photon of the correct energy into this chamber resulted in the de-excitation of an ammonia molecule, producing two photons having the same energy as the initial photon. These two photons could then interact with two more ammonia molecules in excited states, causing them to de-excite and producing four photons. As this process continued, more and more photons, all of the same energy, were produced, thus amplifying the initial photon. By 1953, Townes had produced a working model of the maser.

In 1917, Albert Einstein had developed the idea of "stimulated emission," a process in which a photon that interacts with an atom that is in an "excited," or high-energy, state can induce the emission of a second photon. By 1951, Townes had recognized that Einstein's idea could result in a device to amplify microwaves, starting with one microwave photon and producing a second photon, then allowing each of the photons to produce another, in a cascade effect eventually producing a huge number of microwave photons. Within a few months, Townes and his assistants began building a device that used ammonia molecules in a gas as the emission medium. It took the team until 1953 to produce the first amplification of microwaves using this technique. In their first scientific paper describing their device, Townes and his coauthors called the process "microwave amplification by stimulated emission of radiation," and introduced the acronym "maser" to describe their device.

With the development of the maser, the next logical step was to employ the same physical principles to the amplification of visible light. One challenge was finding the correct atom or molecule, one that had a long-lived excited state at the right energy for the amplification of visible light. In 1957, Townes spoke to Gordon Gould, a graduate student at Columbia University, about Gould's work using visible light to excite thallium atoms. Both men quickly realized that thallium might provide the key to a visible-light, or optical, maser. Townes worked with his brother-in-law, Arthur L. Schawlow, and researchers at Bell Labs. In 1958, Townes and Schawlow, a professor at Stanford University, described how masers could be designed to operate in the visible and infrared regions of the spectrum, but they did not produce a working device.

Gould left Columbia before finishing his degree. He joined the Technical Research Group (TRG), a company that received a grant from the Advanced Research Projects Agency to develop an optical maser. Meanwhile, Theodore Harold Maiman of Hughes Research Laboratories in California thought that he could make an optical maser by exciting the chromium atoms in a ruby crystal. It was Maiman who first succeeded in building a small optical maser, which he demonstrated on May 16, 1960. The device was named the "laser" (light amplification by stimulated emission of radiation).

Townes and Schawlow were awarded a patent for the laser in 1960 based on the designs in their 1958 paper, but a thirty-year patent battle erupted. Gould and TRG challenged the patent. They argued that Gould's notarized notebook entries from 1957 described the operating principles of the laser. Others, including Hughes Research Laboratories, joined in the legal battle, which was not resolved until 1985, when a federal court in Washington, D.C., ordered the Patent Office to issue some of the patents Gould had submitted for the laser. Eventually, Gould was issued forty-eight patents, including one for "optical pumping," the technique used in Maiman's ruby laser.

Townes took a leave of absence from Columbia University from 1959 to 1961 to serve as vice president and director of research of the Institute for Defense Analyses, a nonprofit organization operated by eleven universities that advises the Department of Defense on national security issues, particularly those involving scientific and technical issues. In 1961, Townes was appointed provost at the Massachusetts Institute of Technology (MIT). In 1966, he was named institute professor, the highest honor awarded to MIT faculty. Later that year, he resigned as provost to return to his research. Between 1966 and 1970, Townes chaired the National Aeronautics and Space Administration's Science Advisory Committee for the Apollo program, which led to the first lunar landing.

Townes shared the 1964 Nobel Prize in Physics with two Russian physicists, Nikolay Gennadiyevich Basov and Aleksandr Prokhorov. The prize was awarded for their contributions to quantum electronics that led to the development of the maser and the laser.

Townes left MIT in 1967 to join the faculty at the University of California, Berkeley, where he continued his research in astronomy and defense issues until his retirement in 1986. He developed a technique to use laser light to see through the veil of dust and gas that shields large stars, called red giants, from direct observation. His group used two 65-inch-diameter telescopes on Mount Wilson in California to collect the infrared emission from the red giants. Most of this infrared emission is from the gas and dust surrounding the star. By combining the starlight collected by the telescopes with light from a laser in their laboratory, they could separate out only the starlight at the specific wavelength of the laser light. Looking at only this narrow wavelength range allowed them to see the star through the more intense emission from the gas and dust. One of the red giants they observed, Mira, appeared to be thirty percent larger than astronomers had believed.

Impact

Initially, many people were skeptical that the maser and laser would have practical applications. Although it took a decade or more for lasers to become small and inexpensive, the laser has had an enormous impact on modern society. It is employed in many consumer products, including supermarket checkout scanners, compact disc (CD) and digital video disc (DVD) players and writers, and laser pointers. As a commercial product, the laser is used for fiber-optic communications. Laser surgery, particularly laser eye surgery, has become an important medical procedure. The military has developed weapons systems using lasers and has explored the use of X-ray masers in antimissile defense systems.

The status that Townes gained from his invention allowed him to influence public policy. Townes was a founding member of the Jasons, a group of scientists that provides advice to the Department of Defense, the Department of Energy, and the U.S. intelligence community on scientific and technical issues.

—*George J. Flynn*

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See also: Willard S. Boyle; Gordon Gould; Ali Javan; Theodore Harold Maiman; Arthur L. Schawlow.

Sakichi Toyoda

Japanese mechanical engineer

From 1890 to 1925, Toyoda's inventions revolutionized the Japanese loom to become a globally competitive automatic power machine. He helped Japan to catch up with the Western industrial revolution. His success and vision enabled his son to do the same for Japanese cars by founding Toyota.

Born: February 14, 1867; Yamaguchi (now Kosai), Shizuoka Prefecture, Japan
Died: October 30, 1930; Nagoya, Aichi prefecture, Japan
Primary field: Manufacturing
Primary inventions: Automatic power loom; automatic shuttle-changing device

Early Life

Sakichi Toyoda (sah-kee-chee toh-yoh-dah) was born in rural Japan in 1867, the oldest son of the carpenter Ikichi Toyoda. His native village of Yamaguchi (now Kosai), in Shizuoka Prefecture southeast of Tokyo, was part of Japan's textile region. Here, primarily women weavers manufactured cotton cloth on labor-intensive hand looms to support the family income from rice farming.

Toyoda's boyhood was affected by fundamental changes in Japan. After the United States forced Japan to open itself to Western commerce in 1853 and the shogun abdicated and relinquished power to the Meiji emperor in 1868, Japan embarked on a quest to catch up with the West's industrial revolution. Even in villages, basic schooling became mandatory. Toyoda finished elementary school in 1877. He was then apprenticed to his father.

Unhappy with the traditional life laid out for him, in 1885, at the age of eighteen, Toyoda was electrified when a traveling teacher told of the new Japanese patent law and urged the boys of Yamaguchi to contribute to Japan's technological development. On that day, Toyoda decided to become an inventor.

Reading the translation of British author Samuel Smiles's inspirational *Self-Help* (1859) confirmed Toyoda's choice. He decided to invent an improved loom to benefit life and work of the women weavers of his community. As a carpenter, Toyoda knew about the physical construction of the hand looms in operation, basically unchanged since medieval days. As he lacked a theoretical scientific background, he observed the looms, then made his modifications to models and conducted experiments. He made his inventions by learning through trial and error, a method he used throughout his life.

Toyoda's big break occurred when he attended the Third National Industrial Exhibition in Tokyo in 1890 at age twenty-three. For two weeks, Toyoda observed the foreign power looms on display. He then invented his first new wooden manual loom in the fall of 1890 and patented it in early 1891. Toyoda's invention increased weaver productivity by 50 percent by linking the flying shuttle to the mechanism holding down the yarn just woven.

Life's Work

Toyoda built four or five of his own looms and set up a small weaving factory in Tokyo in 1891. Pressured by his family, he married his first wife, Tami, and tried to earn enough money from his new looms to finance further inventions. However, he found that foreign competition was too fierce. Efficient French hand looms were cheaper, and Western power looms more productive. By the fall of 1893, Toyoda's first business built upon his invention failed, and he moved back to Yamaguchi. Soon, he left to work for an uncle in the commercial city of Nagoya. His son, Kiichiro, was born on June 11, but his marriage to Tami failed. Sakichi kept his son after the divorce.

In late 1894, Toyoda invented a yarn-reeling machine, the foot pedal of which freed one arm of its operator, doubling productivity. In 1895, he opened the Ito Retail Store in Nagoya with his uncle and a third partner. He married again, to Asako Hayashi, who proved an astute businesswoman who managed the store together with Toyoda's younger brother Heikichi.

In 1896, Toyoda's store nearly crashed as a result of the fraud of the third partner. Marshalling all his strength, Toyoda managed to save the store and invent his narrow wooden power loom, which became operational in 1897, the year his daughter, Aiko, was born. For the first time, a Japanese inventor held a patent to a power loom, a milestone in Japan's industrialization.

In 1899, Toyoda sought to set up a business that earned enough revenue to allow him to conduct his expensive research. Together with the Japanese trading conglomerate Mitsui, Toyoda founded the Igeta Shokai (trading) company, with himself as chief engineer. Igeta's business was to produce and sell Toyoda's power looms under a ten-year license agreement.

At Igeta, Toyoda articulated his later famous principle of *kaizen*, or continuous improvement, as he strove to better his inventions. Yet his demand for research funds clashed with the company's goals to save money during an economic downturn. Angrily, in 1902, Toyoda resigned from Igeta, and he returned to his old Ito trading firm he renamed Toyoda Shokai. His wife, Asako, and his second younger brother, Sasuke, managed operation of the company's 138 power looms.

In 1903, Toyoda invented a new automatic shuttle-changing device for his power looms. However, to his big disappointment, his new steel looms failed in an endurance test against the British competition of Platt Brothers and Company in 1905. Part of his problem was that Japanese metallurgy could not yet yield steel of sufficient quality for Toyoda's innovative power looms.

To gain more capital, Toyoda teamed up with Mitsui again. He dissolved his own company and founded Toyoda Loom Works in 1906 with himself as operating manager. Soon, Toyoda clashed again with Mitsui over his research budget. Thoroughly disillusioned, Toyoda resigned again and left for the United States on May 8, 1910, intending to immigrate. However, Japanese American chemist Jokichi Takamine persuaded Toyoda to return to Japan.

In 1911, Toyoda founded the Toyoda Automatic Weaving Factory. In October, 1912, he sold his rights to future earnings from his inventions for a lump sum to finance his ongoing inventions. In 1914, he founded a spinning business and cooperated with Mitsui again.

In his ultimate quest to invent an internationally competitive Japanese power loom, Toyoda relied on friends and family. In October, 1915, his daughter, Aiko, married Risaburo Kodama, younger brother of Mitsui's Ichizo Kodama and a managing talent. Toyoda adopted Risaburo as his son, and in 1918 Risaburo Toyoda became managing director of the newly founded Toyoda Boshoku, a spinning and weaving company.

At the same time, Asako Toyoda made sure that

AUTOMATIC POWER LOOM

Sakichi Toyoda's crowning achievement was the first Japanese automatic power loom, which he patented in 1925. With it, he reached his goal, set when he decided to become an inventor at the age of eighteen, to make Japanese looms competitive with Western imports.

The basis for the 1925 loom was Toyoda's invention of the first Japanese manual power loom in 1896. Instead of human labor, a steam engine attached to a drive shaft provided power to weave the delicate weft yarn from left to right into the strong lengthwise warp yarn and to advance the finished cloth on the loom. The shuttle still had to be changed manually, but this invention represented a quantum leap for Japanese technology.

One of Toyoda's next inventions ensured that the warp yarn was held at constant tension. Finally, working together at a fever pitch with his son, Kiichiro, from November to December, 1924, Toyoda acquired ten new patents that formed the innovative basis of the 1925 automatic power loom. His most crucial invention was the design of an automatic shuttle-exchange system, which Kiichiro developed into a functional device. The Toyoda mechanism joined the front and rear panels of the flying-shuttle box so that both panels were lifted simultaneously when a new shuttle with a fresh bobbin containing new yarn was automatically pushed into the shuttle box and the old shuttle with the empty bobbin was ejected. Because of this invention, the Toyoda loom could replace shuttles very quickly and smoothly and did not stop during the exchange. Other key inventions were a warp let-off device and a mechanism to automatically stop the loom if the weft yarn broke.

The invention of Sakichi and Kiichiro Toyoda provided the Japanese textile industry with great momentum. On automatic Toyoda looms, Japanese weaving companies produced quality textiles for domestic consumption and export, particularly to Asian markets. Manufacture of ever-improved power looms continued to be an important business of the Toyota group. Since 2001, loom manufacture is done by the Toyota Industries Corporation.

Kiichiro Toyoda went to Tokyo University. Kiichiro graduated in mechanical engineering in 1920, part of the new elite of Japanese engineers. After some initial clashes, father and son soon worked as a successful team of inventors. The older Sakichi provided his practical experience, and Kiichiro used his university training to improve on the ideas of his father.

Beginning in 1921, Kiichiro was responsible for giving his father's inventions their final practical shape. Their teamwork was crowned with the success of the first Japanese fully automated loom, patented in 1925. Kiichiro invented a shuttle-change box based on Sakichi's original design. This invention led to the 1926 founding of the Toyoda Automatic Loom Works. There, textile production on the new power looms ran simultaneously with industrial field testing of new inventions.

Recognizing Sakichi Toyoda's achievements as one of Japan's ten most influential inventors of his time, Japanese emperor Hirohito bestowed the Imperial Order of Merit on Toyoda in 1927. Toyoda suffered a mild cerebral hemorrhage later that year.

Turning to what he saw as the next big field for Japanese inventions, Sakichi exhorted Kiichiro to turn to automobile manufacture. To provide his son with the necessary start-up funds, Toyoda sold the worldwide patents of his automatic power loom to the Platt Brothers of Great Britain for ¥1 million, or $150,000. Kiichiro closed the deal on December 24, 1929. This proved sufficient seed money for what would become the Toyota Motor Company in 1937, even though Platt only paid $58,000 at closing and later tried to get out of its commitment. Sakichi Toyoda contracted pneumonia in October, 1930, and died in Nagoya later that month at age sixty-three.

IMPACT

Toyoda was one of the great Japanese inventors who ensured that their country caught up with the Western industrial revolution. Inspired by the spirit of the Meiji Restoration that provided unheard-of opportunities to an inquisitive, intelligent, and restless young man like himself, Toyoda magnificently rose to the occasion. Once he decided to become an inventor, he turned to the field he knew best. He ceaselessly worked to invent ever more efficient Japanese looms, making his country independent of foreign looms. His inventions provided Japan with the means of manufacturing domestic textiles to replace imports and allowed the country to become an exporter of well-spun cotton products.

As an inventor, Toyoda continuously struggled to make his ideas economically viable and successful in a mass industrial setting. Teaming up with financial partners, he always ran into difficulties when resources became scarce. His reliance on his family network laid the foundation for the survival of his companies into future generations. His first wife gave him his son, Kiichiro, who, aided by Sakichi's second wife's insistence on his academic training, would found Toyota Motor Company, slightly changing the family name for a more auspicious Japanese spelling. Through his daughter, Aiko, Toyoda gained an adopted son invaluable for his management capabilities.

Just as Sakichi Toyoda invented Japanese looms that eventually surpassed their Western models in quality and price, so his son's Toyota cars would do the same. Toyoda embodied the ideal of the Meiji era Japanese inventor: Through total commitment to his task, seen as a duty to both nation and community, he lifted Japan into the industrial age. With his visionary decision to shift the focus of his son's inventions from looms to cars, Toyoda ensured that after the dark days of World War II, Toyota cars would gain a world market. His *kaizen* philosophy of continuous invention and process improvement became the business philosophy of Toyota. The company's outstanding success would be widely studied and praised by U.S. corporations and economists.

—*R. C. Lutz*

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See also: Sir Richard Arkwright; James Hargreaves; John Kay.

RICHARD TREVITHICK

English mechanical engineer

Trevithick was the first person to develop a working steam locomotive. The particular application of high-pressure steam that made that application possible also resulted in the stationary steam engine known as the Cornish engine, which obtained far more widespread practical success.

Born: April 13, 1771; Illogan, Cornwall, England
Died: April 22, 1833; Dartford, Kent, England
Primary fields: Mechanical engineering; railway engineering
Primary inventions: Steam locomotive; Cornish engine (steam engine)

EARLY LIFE

Richard Trevithick was the only son and youngest of six children of an identically named father, who was a miner, and his wife, Anna, née Teague. The elder Richard Trevithick worked in numerous copper mines, eventually rising to managerial positions at four mines, including Wheel Treasury and Dolcoath—positions that allowed him to provide initial arenas for his son's technical ingenuity.

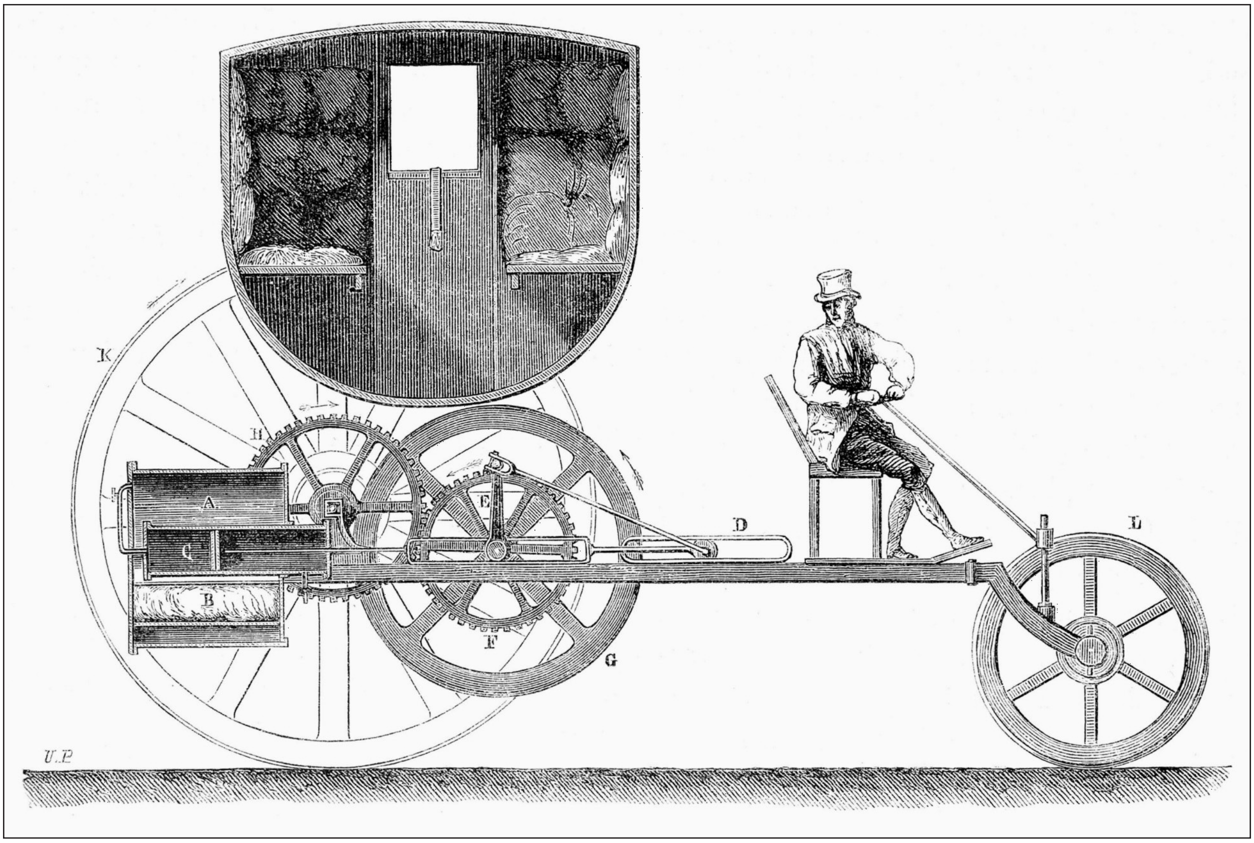
Unsurprisingly, given his situation in the family, the younger Richard was spoiled by his mother and became something of an enfant terrible at elementary school in Camborne. He was tall—six foot, two inches—and strong; in his teens, he became a renowned wrestler and was nicknamed the "Cornish Giant," presumably encouraging his overweening self-confidence even further. On leaving school, he went to work for his father, not as a common miner but as a sort of technical consultant, overseeing the deployment and advising on the potential application of steam engines invented by James Watt, exemplars of which were then being installed in many Cornish mines.

On November 7, 1797, Trevithick married Jane Harvey (1772-1868), the daughter of John Harvey of Hayle Foundry, which produced mining equipment for local use and export. The couple had four sons and two daughters. Trevithick had begun introducing fuel-saving innovations to Watt engines for some years before his marriage, while he was employed at Wheel Treasury, but by the end of 1797—in which year his father died—he was employed as an engineer at the Ding Dong Mine near Penzance, where he began working on an engine designed by William Bull.

LIFE'S WORK

With James Watt's patent—which Watt had defended fiercely—about to expire in 1800, there was much anticipation of the free-for-all that would follow. When Watt named Trevithick as the chief offender against his patents, as his legal defense of them drew to a close the accusation made Trevithick a local hero in Cornwall and gained him the nickname "Cap'n Dick." Trevithick immediately began work on a new kind of steam engine, using much higher pressures than the Watt engine; it was more expensive to construct, but it promised to be much more fuel-efficient—a vital consideration in Cornwall, whose mine owners had to import coal from Wales. Trevithick's engines became known as "puffers" by virtue of the noise they made in operation.

The first operative puffer was probably installed at Dolcoath not long after the elder Richard Trevithick's death, but it was not widely advertised because Watt's patent was still in force. There was certainly one in operation at Cook's Kitchen in 1800, which was still in service in 1870. Trevithick built an advanced model for use at Coalbrookdale in Shropshire in 1802, which operated at the then-unheard-of pressure of 145 pounds per square inch. It was, however, only a matter of time before one of these high-pressure engines exploded, and one did so at Greenwich in 1803, killing four men. Watt and his partner, Matthew Boulton, did their best to capitalize on the public relations disaster, condemning Trevithick machines as inherently unsafe. Trevithick responded by devising new safety mechanisms, including the "fusible



Richard Trevithick's steam carriage of 1801. (The Granger Collection, NewYork)

plug," which remained a standard feature of steam engines thereafter.

Trevithick had long been interested in the problem of building an operable steam locomotive—various models of such machines had been constructed since 1770, but none had proved viable—and he had constructed his own working model in 1797. By that time, he had become acquainted with Davies Giddy (who subsequently changed his surname to Gilbert), a local member of Parliament who took a great interest in local technological initiatives. Giddy funded the construction of a full-scale version at Stephen Williams's foundry near Camborne, whose first public demonstration, on Christmas Eve of 1801, generated sufficient interest to be commemorated in a popular song. Trevithick's first steam locomotive broke down four days after that first demonstration, however, while being moved to a new location, and the team supervising its removal repaired to the local pub, with the result that the boiler overheated and was irreparably damaged.

In spite of this calamity, Trevithick succeeded—with the help of one of his backers, Andrew Vivian, and another protégé of Giddy, Humphry Davy—in securing a patent for the locomotive on March 24, 1802. A second locomotive built at Camborne in 1803 was successfully transported to London, but it too broke down. Vivian then withdrew his support, but Tevithick persisted, building the first railway locomotive at Pennydarren Ironworks near Merthyr Tydvil, where he was then employed as an engineer. It had its first successful trial on February 13, 1804, but the poor condition of the track resulted in continual derailments, and it was relegated to work as a stationary engine.

Because of his difficulties in constructing a viable locomotive, Trevithick's work with high-pressure engines began to concentrate increasingly on the improvement of the boilers; it was this that led to the development after 1806 of the so-called Cornish engine, which was first put to work at Dolcoath in 1812 and whose clones subsequently spread far and wide throughout the world. Had Trevithick stuck to stationary engines thereafter, he might have become much more prosperous, but locomotives had become his primary passion. His second railway locomotive, nicknamed *Catch-Me-Who-Can*, was established on a circular track near Gower Street in London for the purposes of advertisement. It obtained some popular renown as a "steam circus" charging for rides but did not attract further financial backing. Trevithick apparently lost heart, abruptly abandoning the project. That too proved to be a disastrous mistake; his assistant, John Steele, carried the project forward alone, building new engines to Trevithick's design, and the establishment of one of these at Wylam in northeast England prompted George and Robert Stephenson to build their own rival, the *Rocket*. In the meantime, Trevithick's career began a downward trajectory from which it never recovered.

Between 1803 and 1807, Trevithick also worked on a steam dredger for use in the Thames, and he involved himself in a project to build a tunnel under the river from Rotherhithe. When the tunnel collapsed and was flooded in August, 1807, Trevithick might have gone home, or traveled to the northeast to work with the Stephensons, but instead he went into business with a merchant involved in trade with the West Indies, Robert Dickinson. The workshop they established in Limehouse generated several patent applications, including one for a "nautical laborer"—a steam tug equipped with a crane—but nothing came of any of them. Trevithick contracted typhus in 1810, and the business was declared bankrupt in February, 1811. Although Trevithick did return to Cornwall briefly to resume work on the development of the Cornish engine, he could not settle. He became interested in South American silver mining, and in 1814 he was hired by Francisco Uvillé to build an engine for use in a mine in Peru.

There was no need for Trevithick to follow his engine to Peru, but he set sail in September, arriving in February, 1817, arriving to an extravagant reception. He soon fell out with Uvillé, though, and began roaming the war-torn continent. He was briefly attached to Simón Bolívar's army as a military engineer but was forced to flee after a disastrous defeat. He took over Uvillé's mine when the latter died in 1818, but the war followed him and the site became a battlefield. He traveled to Costa Rica thereafter, entering into partnership with a man named James Gerard and staking claims on several potential mining sites, but he could not find backing for their exploitation. He wound up in Cartagena, Colombia, destitute, but there had the remarkable good fortune to run into Robert Stephenson, who paid for his passage home.

Trevithick received a warm welcome in Cornwall—where his wife was still waiting for him, in conditions of abject poverty—when he arrived there in October, 1827, but his attempts to find backers for further projects failed dismally. He was reportedly offered several thousand pounds for his claims but refused to sell. He made plans with Gerard to set out for Costa Rica once again, but Gerard died and the plans came to naught. Instead, Trevithick went to the Netherlands to advise on the application of steam engines to land drainage—apparently with some success, although new plans he drew up for a ship powered by a water jet were stillborn. He continued to apply for patents, filing one for an engine using superheated steam (1832), but he had to return to England to work on a machine designed by John Hall in Dartford in Kent. There he fell ill, dying in his lodgings in April,

THE STEAM LOCOMOTIVE

Steam locomotives were impracticable using Watt engines, because the relatively low pressures used by those engines were inadequate for the purpose of propulsion. The use of higher pressures overcame that problem but brought with it corollary problems of strengthening and securing the boilers. The "Cornish boiler" that Richard Trevithick developed for eventual use in the so-called Cornish engine was a horizontal cylinder with a fire tube running through the middle; these design modifications not only proved extremely useful in stationary machines but also permitted Trevithick's first full-scale steam carriage to attain a velocity of between five and nine miles per hour. The subsequent history of Trevithick's locomotives was, however, a tale of tragic ifs and buts.

If Trevithick's first and second steam carriages had not broke down on inadequate roads, and if the first designed to run on a railway had not found the track just as inadequate as the road, his enthusiasm might not have become so fragile as to shatter when the Gower Street "steam circus" failed to win immediate backing. John Steele demonstrated that if Trevithick had only persisted—even if that meant going into partnership with George and Robert Stephenson—he could have not only retained his credit for the invention but also made his fortune from it. Unfortunately, he lost heart at exactly the wrong moment and set out instead on the road to ruin. Meanwhile, the improved version of his machine that the Stephensons built became the prototype of a vast number of future machines as well as the foundation stone of the railways that transformed the communications of Victorian Britain, Europe, and the rapidly expanding United States.

1833; his workmates had to club together to pay for his burial in an unmarked grave. His wife, meanwhile, continued to support her children as best she could.

IMPACT

Trevithick represents the downside of the early nineteenth century enterprise culture; his eventual failure to exploit his technological innovations resulted in his being relegated to the sidelines of the history of the Industrial Revolution. He was undoubtedly a brilliant engineer who fully deserved his brief celebrity, but his crucial decision to abandon the steam locomotive and concentrate on other projects proved fatal to his fortune and fame alike. He retains the credit for devising the Cornish engine, but that was never going to eclipse the honor given to James Watt as the inventor of its inferior predecessor.

One can only speculate as to Trevithick's reason for his stubborn determination to stay as far away from his wife and his home as possible after 1802, but whatever the reason was, it did not prevent his sons from attempting to follow in his footsteps. One of them, Francis, became the chief engineer of the London and North-Western Railway Company, while another, Frederick Henry, constructed the floating steam bridge between Portsmouth and Gosport in 1864. Francis also wrote a biography of his father, hailing him as the inventor of the steam locomotive, but it came too late to rescue his reputation; George and Robert Stephenson had already grabbed all the glory.

—*Brian Stableford*

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See also: Nicolas-Joseph Cugnot; William Murdock; George Stephenson; James Watt.

KONSTANTIN TSIOLKOVSKY

Russian rocket scientist

Tsiolkovsky was the first man to design rocket-powered vehicles and life-support systems for space travel, and to promote the idea of the colonization of space by means of the construction of artificial Earth satellites.

Born: September 17, 1857; Izhevskoye, Russia
Died: September 19, 1935; Kaluga, Soviet Union (now in Russia)
Also known as: Konstantin Eduardovich Tsiolkovsky (full name)
Primary field: Aeronautics and aerospace technology
Primary inventions: Space-traveling projectiles; rocket propulsion design

EARLY LIFE

Konstantin Eduardovich Tsiolkovsky (KON-stuhn-teen ehd-WAHR-duh-vihch tsyawl-KAWF-skee) was the son of Eduard Tsiolkovsky, a Polish forester who had migrated to Russia, and his wife, Maria, née Yumasheva; their family was poor but large, Konstantin being one of eighteen children. At the age of ten, he suffered a bad bout of scarlet fever and was left with hearing difficulties, with the result that he did not go to school and was forced to educate himself. In 1873, he went to Moscow to complete this course of self-education, and he was taken under the wing of the futurist philosopher Nikolai Fyodorovich Fyodorov, who was then working in a Moscow library. Fyodorov was enthusiastic about the possibilities of radical life extension, technological resurrection, and the colonization of space, which he believed to be essential steps in the progressive improvement of humankind.

Fyodorov's ideas left a deep impression on Tsiolkovsky, who remained the older man's fervent disciple

SPACE-TRAVELING PROJECTILES

Konstantin Tsiolkovsky's first design for a spaceship, contained in his 1883 monograph *Svobodnoe prostranstvo* (free space), depicts a spherical vessel propelled by the recoil of shots fired from a cannon mounted in the rear. The most interesting aspect of that design is not the propulsion system but the gyroscopes employed to modify the orientation of the vessel. Tsiolkovsky modified this design progressively in his later works, substituting more sophisticated devices for the crude cannon and modifying the shape of the shell into an elongated ellipse.

The first experimental design described in *Vne zemli* (1920; *Outside the Earth*, 1963) is of a vehicle variously described as "egg-shaped" and "cigar-shaped" whose liquid propellants burn in a carefully measured fashion to produce a uniform gaseous jet, which is directed through an "exhaust nozzle," thus resembling the rockets then in use as fireworks and weapons of war. The text is deliberately vague regarding the formula of the propellant fuel, admitting that then familiar fuels, whether solid, liquid, or gaseous, were inadequate to the task of accelerating a projectile to the velocity required to escape Earth's gravitational attraction, but insisting that a new, highly flammable combination of two liquids has been recently discovered that could serve as a propellant.

The rocket in which the actual ascent described in the novel is made is a more advanced "compound" form made up twenty separate sections—what would now be called "stages." The whole structure forms an elongated and "streamlined" body about one hundred meters long and four meters in diameter, the exhaust nozzles being mounted in pipes coiled around the hull, whose rotational effect gives the rocked greater stability in forward movement. The rocket ship's shell has three layers, the outer one functioning as a kind of heat shield, radiating frictional heat into space, while the second layer is resistant to conduction and the third embodies a cooling system. In addition to a supply of oxygen, its cargo includes water suspension chambers to protect the crew members from the effects of the initial acceleration and space suits for subsequent use outside the vessel.

Tsiolkovsky's subsequent essays and scientific papers made little further modification to the hulls of his rocket ships, although the compound structure and abundant equipment were greatly simplified. Among the innovative details he introduced was a "gas rudder" fitted over the exhaust nozzles from which the reaction gases were blasted, which was supposed to allow the spaceship to be steered; this device appears in various sketches made in the 1930's.

Although all these designs were hypothetical, they anticipated all the major problems associated with manned spaceflight, and they made some attempt to solve them. Friedrich Zander and his colleagues, who carried out the actual experimental test of early Soviet rockets, made only slight modifications to his designs. Although Tsiolkovsky's own representation of a multistage rocket left something to be desired, his anticipation of the principle was highly significant, and his conviction that new combinations of liquids might ultimately produce a viable fuel proved to be correct.

when Tsiolkovsky left Moscow in 1876. He lived briefly in Vyatka and Ryasan before applying to work as an elementary school teacher. While waiting for his appointment to be confirmed, he filled a notebook with designs for propulsion systems and life-support systems that might facilitate space travel. He taught at a school in Borovsk from 1879 until 1892 and married the daughter of a local priest, Barbara E. Sokolova, while he was there; they had four sons and three daughters.

LIFE'S WORK

Tsiolkovsky's speculations regarding the practicalities of space travel led him to conclude that the principle of jet propulsion was the most likely means of its achievement. He adopted this opinion from the outset, in the notebook he began to write in 1878. While he was working in Borovsk, he further developed those ideas into an 1883 monograph titled *Svobodnoe prostranstvo* (free space). He followed this up with many other papers, including one on "How to Protect Fragile and Delicate Objects from Jolts and Shocks" (1891). In 1892, he was transferred to a larger elementary school in the provincial town of Kaluga, where he met other people with scientific interests, and his ideas began to gain wider circulation.

In 1895, Tsiolkovsky compiled a collection of didactic science-fiction stories and speculative essays translated as *Dreams of the Earth and Sky and the Effects of Universal Gravitation*, in which he extended his speculations to the possibility of building an artificial satellite for scientific purposes. He suggested that it might be provided with power by means of "solar motors," and he devoted a good deal of attention to the life-support systems that it would require. Tsiolkovsky produced a technical analysis of "The Exploration of Cosmic Space by Means of Reaction-Propelled Apparatus" shortly after the turn of the century, whose first chapters were published in *Nauchnoye Obozrenie* (science review) in 1903. It contained his first detailed design for a rocket, but the article was slightly garbled by the printers and the magazine was suppressed by the authorities before publication was completed. It was not until 1911 that the next part appeared in *Vestnik Vozdukhoplavania* (herald of aeronautics), where it attracted much more attention in a burgeoning community of aeronautical engineers. The article included the "Tsiolkovsky rocket equation" for calculating escape velocity.

Tsiolkovsky attempted to popularize his ideas further by completing a didactic science-fiction novel that he had begun in 1896, *Vne zemli* (initially translated into English as *Beyond the Planet Earth* in 1960, then as *Outside the Earth* in 1963), describing an epoch-making space journey and its Fyodorovian aftermath. Its publication in 1916 was interrupted, however, when the magazine serializing it ceased publication; the problems and shortages associated with the Russian Revolution of 1917 prevented its appearance as a book until 1920. Its account of the first stages in the colonization of the solar system fully entitles Tsiolkovsky to be retrospectively recognized as the originator of the myth of the space age, although the original prospectus had been Fyodorov's. The story also imagines the inauguration of an international scientific fellowship, whose crew members on the expedition all bear the surnames of famous scientists of their homelands' past; thus, Galileo, Newton, Helmholtz, Laplace, and Franklin take their places in the epoch-making rocket alongside the Russian engineer Ivanov.

Tsiolovosky became a member of the Soviet Academy of Sciences in 1919 and was awarded a pension by the Soviet government in 1920, which allowed him to give up teaching, although he continued to live in Kaluga. When his ideas regarding the practicalities of space travel were echoed elsewhere—notably in a book by Hermann Oberth, the founder of the German Rocket Society, in 1923—Tsiolkovsky was contacted by Friedrich Zander, who had also published works on the theory of rocket travel and life-support systems in 1908-1911. The Soviet authorities, who were then taking a strong interest in the development of aeronautics, appointed Tsiolkovsky as a professor at a newly formed Military Air Academy on August 23, 1924; he, Zander, and Yuri Kondratyuk immediately established a Soviet Society for the Study of Interplanetary Travel in imitation of the German Rocket Society.

In 1926, Tsiolkovsky published a definitive book updating his earlier essay, whose title translates as *The Exploration of Space by Reaction-Propelled Devices*. The Soviet government began sponsoring rocket tests in 1930; although Tsiolkovsky—who was then nearing seventy—was not directly involved, Zander was in charge of one of the programs, and the designs employed were based on those Tsiolkovsky had first committed to paper thirty years before. Tsiolkovsky continued writing until his death in 1935, attempting to summarize his own version of Fyodorov's visionary philosophy in *The Cosmic Philosophy* (1932), which proposed that the end of progress would be the happiness of all the thinking beings in the galaxy, which would involve the formation of a galactic community and the colonization of all its potential habitats. Tsiolkovsky's *Collected Works* were issued by the U.S.S.R. Academy of Science Publishing House in 1954. His science-fiction stories and some of his speculative essays were reprinted in the showcase omnibus *Put'k zbezdam* (1960), which was translated into English as *The Call of the Cosmos* in 1963.

IMPACT

Tsiolkovsky's crucial contribution to space research was recognized by the placing of an obelisk over his grave in Kaluga, inscribed with a quotation that translates, "Man will not always stay on Earth; the pursuit of light and space will lead him to penetrate the bounds of the atmosphere, timidly at first but in the end to conquer the whole of solar space." Another monument to him was established in Leningradsky Prospekt in Moscow to mark the centenary of his birth; a few weeks later, on October 4, 1957, *Sputnik*—the first artificial Earth satellite—was launched, apparently initiating the space age of which he had dreamed.

The Fyodorovian notion that the future of humankind would consist of a biotechnologically assisted expansion into space and the gradual colonization of the galaxy was echoed elsewhere in Europe and—much more fervently—in the United States, where it became the standard mythical future of generic science fiction. Tsiolkovsky was not responsible for that diffusion of ideas, but he was responsible for the fact that the Soviet Union became involved in rocket research at an early stage and pushed that research forward so determinedly. His ideas helped to give the Soviet Union a lead in the space race that developed after World War II, and the United States would not have made such rapid progress in space technology had it not been spurred on by that political competition. However indirectly, Tsiolkovsky played a major role in the chain of causation that led the United States to land a man on the Moon in 1969.

—*Brian Stableford*

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See also: Wernher von Braun; Robert H. Goddard.

JETHRO TULL

English agriculturist

Tull, often hailed as the "father of British agriculture," paved the way for the late eighteenth century agricultural revolution in England by inventing the seed drill, which resulted in increased crop yields (up to eightfold) and greater weed control over earlier hand-broadcasting methods.

Born: March 30, 1674 (baptized); Bradfield, near Basildon, Berkshire, England
Died: February 21, 1741; Prosperous Farm, near Hungerford, Berkshire, England
Primary field: Agriculture
Primary invention: Tull seed drill

EARLY LIFE

Jethro Tull was born in rural Berkshire, England, but his father, also named Jethro, and his mother, Diana Buckridge Tull, hoped he would train for public service rather than farming. He matriculated at St. John's College, Oxford, but finished without taking a degree, instead pursuing legal studies at Gray's Inn in London. When ill health interrupted his studies, he settled down to farm with his father on the family estate at Howberry. He also married Susannah Smith of Warwickshire, with whom he had a son, John, and a daughter, Susannah.

In the eighteenth century, the title "farmer" implied a gentleman who directed other men and women, not a laborer. As bailiff, or field supervisor, Tull was frustrated

Jethro Tull. (Library of Congress)

by the field hands' inability to plant seeds in a consistent, measured depth. In 1701, he invented a machine to do what his workers could not (or would not). Tull did not promote his invention, and it remained known only to his circle until circumstances forced him to move his family. In 1711, Tull's increasing illness (a weak heart) drove him to take a convalescence tour of the Continent, where he studied current European farming methods. Returning in 1714, he found the farm's revenue insufficient to cover the expenses of his three years in Europe. He sold the acreage and moved his family to a more modest farm near Hungerford, where he improved his machine and his methods, based on what he had seen in Europe.

LIFE'S WORK

Tull's seed drill might have remained a local innovation were it not for the enthusiasm of his Hungerford neighbors when he moved there in 1714. They encouraged him to publicize the success of his planting technique. Not conversant with the scientific community, however, Tull could think of no method of disseminating his ideas beyond publishing a book, which he could not afford to do. With his farm barely supporting his family, Tull decided to continue his legal studies, and he was admitted to the bar in 1724. About that time, he began writing a full account of his invention and his agricultural system. By 1731, he had finished his manuscript but could still not afford to publish a full-length book, so he had an eighty-one-page "specimen" published cheaply in Dublin under the title *The New Horse-Houghing Husbandry: Or, An Essay on the Principles of Tillage and Vegetation Wherein Is Shewn, a Method of Introducing a Sort of Vinyard-Culture into the Corn-Fields, in Order to Increase Their Product, and Diminish the Common Expence, by the Use of Instruments Lately Invented*. In two years, the sales of this pamphlet justified the publication of an expanded two-hundred-page volume under virtually the same title, and Tull's place in the history of agriculture was assured.

In the interim, influential noblemen had become interested in what became playfully known as "Tullian" agriculture. Tull had criticized the fact that English farmers were still using the "Virgilian" methods described by the Roman poet Virgil (70-19 B.C.E.) in his *Georgics* (37-29 B.C.E.), popularized in his day by John Dryden's translation. Eighteenth century wits noted the irony that the adjective applied to Virgil's near-contemporary Cicero (106-43 B.C.E.) in earlier times had been "Tullian" (for Marcus Tullius Cicero). In 1729, the Scottish Lord Ducie (Matthew Ducie Moreton, 1663-1735) introduced what he called Tullian or "Anti-Virgilian" methods to Charles, Eighth Lord Cathcart (1686-1740), the Parliamentarian in the House of Lords most active in agricultural concerns. On May 9, 1730, Lord Cathcart took a party of noble

THE TULL SEED DRILL

Jethro Tull's first seed drill was constructed on the frame of a wheelbarrow. He removed the gudgeon—the metal cylinder mounted on the wheel's axle that allowed it to turn independently of the wheel—and replaced it with a larger cylinder with holes drilled at intervals. This perforated cylinder was fitted into the trough of the wheelbarrow, into which a slot was cut opposite the gudgeon. As the cylinder turned, its holes would pick up one seed at a time from the trough and drop them into a tube. This was the basic design, but Tull did not stop there.

The rotating cylinder reminded Tull of the groove, tongue, and spring of the sounding board of a church organ he had worked on, so he replaced his crude perforated cylinder with a much more closely fitted one made from the foot pedal of an old organ. Having mechanized the placement of the seed, Tull realized that mechanization allows duplication. A wheelbarrow could only accommodate one row at a time; enlarging the frame could allow simultaneous deposit of multiple rows of seed. Doing so, however, would create a machine too heavy for one farmer to push. English farmers of the time generally used oxen to plow their fields. Tull designed his second-generation, three-row (and later four-row) seed drill to be pulled by the lighter and smaller horse. However, the seed was only the middle part of the process. Ahead of his enlarged drill, Tull mounted three plowshares, which opened furrows immediately ahead of each seed depositor. Then, after the seed was dropped, a metal disk known as a coulter turned behind each row to place the soil back over the newly planted seed, spacing the rows widely enough to allow horse-drawn hoes to weed the fields once the crop germinated.

For the next two centuries, the only improvements on Tull's drill was simply increasing the number of rows: Tull's horse-drawn model remained basically unchanged until the 1930's, when they were attached to tractors. Twenty-first century seed drills move the seed by pneumatic tubes and inject them into the soil by air pressure. Nevertheless, other than the switch from Tull's gravity-feed (which remained in use to the end of the twentieth century), modern seed drills still employ the principles Tull had perfected by the early 1700's.

lords to meet with Tull and discuss his theories and results. Thus, when Tull's pamphlet appeared a year later, a great number of influential policy makers were prepared to read it with interest.

Although the Tull seed drill soon became the standard implement for planting in Europe and its colonies, the complete adoption of Jethro Tull's agricultural method was delayed by controversy. The controversy was well founded, for one of Tull's theoretical assumptions was wrong. He opposed the use of animal waste as fertilizer, convinced, first, that the soil contained all of the nutrients grains needed and that it needed only to be pulverized to release the nutrients to the germinating seed; and second, that animal waste contained unwanted seeds that would compete with the grain seed. His first assumption was not completely accurate: Preparing the soil did release more of the nutrients, which explained the success of Tull's experiments, but he was not aware that the grains would eventually exhaust the nitrogen from the soil, which animal manure replaced. His second assumption, however, was correct, and the resultant weed control of Tull's method—weed seeds were no longer spread through animal dung—was an important factor in its success.

Weed control was not just a function of the elimination of fertilizer, however. The regular spacing that resulted from the use of the seed drill meant that weeds could be removed from the spaces between rows without harming the planted grain. In modern times, it is taken for granted that fields are planted in rows, but before Tull's seed drill planting was done by broadcast in a random fashion. The waste involved in this method—some landing on rocks or dry soil, some being eaten by birds—was considered unavoidable, which is the point of the familiar New Testament parable of the sower (Matthew 13:1-23, Mark 4:1-20, Luke 8:1-15). Tull's machine, however, placed each seed at an ideal, uniform depth and immediately covered it over with soil.

The seed drill was not the only Tull invention that would become standard throughout Europe by the end of the eighteenth century. Tull also invented a plow that was essentially a horse-drawn hoe, with the blade elevated so that it uprooted grass and weeds, leaving them on the surface of cultivated land so that they could be gathered and destroyed (rather than reseeding). It is significant that the title of Tull's work emphasized the plowing and hoeing rather than the planting aspect of his method.

Tull never lived to see his agricultural methods become standard, as they were by the end of the century. His financial struggles continued to the end of his life, exacerbated by a profligate son John, who ended up in Fleet Prison, London, for debt, shortly after Tull died penniless in 1741.

IMPACT

Though the process of dropping grain individually through a tube pressed into the ground was known in ancient Babylon (as early as 1500 B.C.E.), European farming had reverted to the broadcast method used by the ancient Romans and continued until Tull's day. Tull's innovation, therefore, lay not in the subsoil drilling but in the mechanical regularizing of the depth and distribution of seeds, as well as the simultaneous removal of weeds that would compete with the seed for nutrients, and covering over the seeds immediately after placement, to keep birds from eating them before they could germinate. By the end of the eighteenth century, agricultural authorities were still divided on whether the Tullian method worked, but influential authors such as John Randall in *The Semi-Virgilian Husbandry* (1764) and Francis Forbes in *The Modern Improvements in Agriculture* (1784) promoted it.

With the rise of industrial manufacturing in England, mass-production of the Tull seed drill became a key to its standardization, and James Smyth and Sons began producing modified Tull drills in 1800, continuing into the middle of the twentieth century. The invention of the subsoil plow in the 1830's improved Tull's drill and was seen to be an extension of his theory that tillage was more important than manuring; as late as 1859, Alexander Burnett's *Tillage a Substitute for Manure* presented the new soil aeration as an extension of *The Precepts and Practice of Jethro Tull*. Twentieth century planters continued Tull's basic design, though the emphasis in weed control shifted from hoeing to fertilizing. The increasing popularity of organic farming methods began to reverse that trend in the early twenty-first century, making plant culture in the United Kingdom, particularly in wheat, closer to the process Tull knew than it had been only fifty years earlier.

—John R. Holmes

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See also: Andrew Jackson Beard; John Deere; Cyrus Hall McCormick.

ANDREI NIKOLAYEVICH TUPOLEV

Russian aircraft designer

Tupolev was among the world's leading designers of military and civilian aircraft. He designed more than one hundred airplanes, which set nearly eighty world records.

Born: November 10, 1888; Pustomazovo, Russia
Died: December 23, 1972; Moscow, Soviet Union (now in Russia)
Primary fields: Aeronautics and aerospace technology; manufacturing
Primary invention: Military and commercial aircraft

EARLY LIFE

Andrei Nikolayevich Tupolev (ahn-DRAY-ee neek-eh-LAY-yehv-yihch TEW-pohl-yihf) was born in the small village of Pustomazovo, near Kimry, Tver region, Russia. He was the sixth of seven children. His early education was entirely at home, but he later attended the Tver Gymnasium, where he excelled, graduating in 1908. He then applied to two major Russian universities: the Imperial Moscow Technical School (IMTU) and the Institute of Railway Engineers. He enrolled at IMTU, where he studied aviation with Nikolai Yegorovich Zhukovsky, the Russian aerodynamic pioneer. While at IMTU, Tupolev built one of the world's first wind tunnels, which formed the heart of the IMTU aviation laboratory.

Andrei Nikolayevich Tupolev. (Library of Congress)

The Russian universities were hotbeds of revolutionary activities, and Tupolev was accused of antigovernment activity and arrested in 1911. He avoided prison on the condition that he remain with his family in Pustomazovo. He studied privately at home and was allowed to return to IMTU in 1914. He wrote his thesis on the development of seaplanes and was granted his degree in 1918.

LIFE'S WORK

Tupolev's life work was done at the Central Aero-Hydrodynamics Institute (TsAGI) in Moscow from 1929 to 1972, the year he died. The Central Design Office (TsKB) within this institute produced large aircraft—bombers and airliners. In the 1930's, Tupolev based much of his work on the all-metal designs of German engineer Hugo Junkers, and these prevailed until World War II. Throughout the 1930's, the number of fully trained airplane designers increased, and Tupolev began producing his designs (designated with the prefix "ANT," based on his initials) out of his own office.

During the Stalinist military purges of the late 1930's, Tupolev and his associate, Vladimir Petlyakov, were arrested on false charges that they had participated in an anti-Soviet "Russian Fascist Party." As World War II began in 1939, Tupolev's talents were so badly needed that he was transferred to a secret research laboratory within the Soviet Union's labor camp system operated by the secret police (NKVD). The laboratory was located near the Moscow suburb of Bol'shevo, and many people from TsAGI were already working there. After this laboratory was moved to Moscow, Tupolev was finally tried, convicted, and sentenced to ten years in prison, but he was released in 1944 to conduct vital defense work.

During this period, Tupolev's greatest success came in dismantling, rebuilding, and redesigning the Boeing B-29, the most advanced bomber at that time. This process, known as reverse engineering, was a daunting task. Three such planes were forced to land in Siberia during the Japanese air raids of 1944. Using these three models, Tupolev was able to mass-produce the Russian version, named the Tu-4, in time for the May Day festivities in 1947—much to the chagrin of the Americans. Tupolev continued to design a number of large aircraft. He shifted from piston-driven propeller aircraft to turboprop planes in the early 1950's. By the time Nikita S. Khrushchev came to power in 1953, Tupolev had produced his unique strategic bomber, the Tu-95. Khrushchev denounced Stalin's terror and, holding Tupolev in high esteem, removed his arrest record. During this time, Tupolev was able to use Khrushchev's support to fend off rival designs from Vladimir Myasischev, who was working on his M-4 series of jet-powered strategic bombers.

In 1955, Tupolev introduced the Tu-104, one of the world's first jet airliners to provide regular passenger service. It was the only jet airliner in service in the world from 1956 to late 1958. Tupolev produced a series of other "Tu" jet passenger planes, and his son Alexei, codesigned the supersonic Tu-144, which made its first flight in 1968.

Khrushchev lost power in 1964, and Tupolev gradually lost his most significant positions to his rival designers. The Tu-144 continued to have prominent support until 1973, and the Tu-154 was also appreciated as a significant design. However, it was clear that the aging Tupolev had lost—and would never regain—his position as the premier large aircraft designer. The Russian design bureau Ilyushin had taken his place. Tupolev died on December 23, 1972, and was interred in Novodevichy Cemetery in Moscow.

THE TUPOLEV TU-144

In 1909, as a twenty-one-year-old college student, Andrei Nikolayevich Tupolev began his lifelong career as a pioneer airplane designer by building Russia's first, and one of the world's first, wind tunnels—just six years after Wilbur and Orville Wright used their wind tunnel to test the world's first heavier-than-air, gasoline-powered airplane. Tupolev would go on to produce some of the world's most impressive aircraft, including the Tu-4, reverse-engineered from Boeing B-29 Superfortresses; the Tu-104, one of the world's first jet transports to provide regular passenger service; and the Tu-144, the world's first supersonic transport aircraft.

The Tu-144 was designed by Tupolev and his son Alexei and made its first flight on December 31, 1968. Tupolev was eighty. The aircraft had swept wings and a nose section that could be "drooped" to improve visibility. It was capable of speeds up to 1,500 miles per hour, more than twice the speed of sound, which it first exceeded in June, 1969. By 1971, it was in production. At the Paris Air Show in June, 1973, the aircraft crashed, killing the flight crew. Apparently, the crash was not caused by aircraft failure, but the negative publicity generated by the disaster hurt production. Following another crash in 1978, the Tu-144 was retired.

IMPACT

Tupolev was one of the world's greatest aircraft designers of the twentieth century. Although some of his work was based on earlier German designs and the Tu-4 was reverse-engineered from the U.S. B-29, during his career Tupolev came up with many unique designs. Despite his prison sentence under Stalin, he was one of the most decorated Soviet aircraft designers. He was made a member of the Soviet Academy of Sciences in 1953 and three times named a Hero of Socialist Labor, in 1945, 1957, and 1972. Tupolev's impact on Russian aviation is unparalleled. Almost every twentieth century Russian aviation giant, from Pavel Sukhoi, famous for his jet fighters, to Sergey Korolev, the space rocket designer, studied under Tupolev. Though a communist hero, Tupolev was so widely accepted as an international aviation pioneer that he was made an honorary member of the top British and American aeronautical organizations. At intervals during his career, Tupolev's designs were often the world's best, and they earned a total of seventy-eight world records.

—Richard L. Wilson

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See also: Glenn H. Curtiss; Hans Joachim Pabst von Ohain; Burt Rutan; Igor Sikorsky; Sir Frank Whittle.

EARL S. TUPPER

American entrepreneur and landscaper

Employing new plastics technology and innovative marketing techniques, Tupper revolutionized food storage and preparation with his Tupperware containers, creating a cultural and economic phenomenon that endured into the twenty-first century.

Born: July 28, 1907; Berlin, New Hampshire
Died: October 5, 1983; San José, Costa Rica
Also known as: Earl Silas Tupper (full name)
Primary field: Household products
Primary invention: Tupperware

EARLY LIFE

Earl Silas Tupper was born to Earnest Leslie Tupper and Lulu Clark Tupper on a farm in rural New Hampshire in 1907. His family struggled financially and moved frequently during his childhood, settling in rural Massachusetts in the early 1920's and establishing a greenhouse business. A mediocre student who barely finished high school, Tupper nevertheless was an ambitious teenager with a strong work ethic and a dream of achieving fame and wealth as an inventor and entrepreneur. His father was an aspiring inventor who was granted a patent for a device to facilitate the cleaning of chickens, and Tupper, though reportedly harboring resentment of his father for his lack of ambition, shared his love for invention, filling numerous notebooks with ideas and sketches. Some, such as his idea for a fish-powered boat, appeared impractical; others, such as his suggestion that his parents open a free playground for the children of their greenhouse customers, would prove to be ahead of their time.

Tupper married in 1931, and he continued his efforts to create and market new inventions while operating a landscaping and tree surgery business to support himself and his family. His business folded during the Great Depression. After declaring bankruptcy, Tupper was forced to take a job in a plastics factory owned by the DuPont Corporation. Despite falling on hard times, he retained his ambition of becoming an entrepreneur, purchasing some used plastic-molding machines from his employer and establishing his own plastic container business in 1938. His company, Tupper Plastics, achieved modest success as a subcontractor for DuPont, making parts for gas masks and other devices for military use.

Tupperware-style storage containers and a basin from 1953. (Getty Images)

Life's Work

After World War II, Tupper experimented with manufacturing various products for the bourgeoning postwar consumer market, including plastic cups, cigarette cases, and soap dishes. Yet he would realize his life's ambition by applying his knowledge of plastics to the development of new means of food storage. His experimentation in plastics refinement led to the development of the Wonderbowl, the first practical plastic food-storage container, in 1946. Realizing the potential of the Wonderbowl, Tupper marketed it vigorously to retailers, but he realized little initial success and continued to struggle financially.

During the late 1940's, Tupper would establish a business relationship with Brownie Wise, a Florida woman who had begun selling Tupperware as a sideline to her work as a distributor for Stanley Home Products. Along with Ann and Thomas Damigella, a Massachusetts couple who also sold Stanley Home Products, Wise attracted the attention of Tupper by selling large amounts of Tupperware products through home parties, a direct marketing technique employed by Stanley in which sellers would invite friends and neighbors into their homes for informal gatherings that included product demonstrations and sales presentations. Wise modified and expanded upon the home party model to create a network of Tupperware distributors and salespeople composed almost entirely of women, a large percentage of whom did not work outside the home. Through this network, Wise realized sales of Tupperware products that outstripped those of other distributors and retailers. Because of the success of Wise and the Damigellas, Tupper decided to market Tupperware products exclusively through home parties.

Tupper met with Wise, the Damigellas, and others in 1948 to create Tupperware Home Parties, Inc., making Wise the head of sales. Wise would continue to refine the home party model and build a nationwide network of salespeople and distributors during the 1950's, making Tupperware a household word and a symbol of both the emerging postwar consumer culture and the changing role of women in American culture. The Tupperware party performed several functions: disseminating information about an innovative product whose uses and benefits were not readily apparent to retail shoppers, empowering women to supplement their household incomes and achieve a measure of independence as businesspeople, and providing a social outlet that proved particularly useful in an increasingly mobile postwar society, as women often attended Tupperware parties to establish or solidify relationships with neighbors.

With his sales division thriving and its operation delegated to a trusted leader, Tupper again focused his creative energy on product development during the early and mid-1950's. Consistent with his reputation for strict, detail-oriented management, Tupper closely supervised every detail of the operation of his factory and personally designed each new product, which was then tested in demonstration kitchens in the factory and introduced to the public at home parties. Wise remained the most visible figure in the Tupperware company, attracting media attention as a master marketer and attaining status as one of the most successful American businesswomen of the 1950's. Wise built a network of salespeople and distributors through an elaborate system of rewards, many of which were presented during lavish "jubilees" that showered top sellers with praise and material rewards. As the phenomenon of the Tupperware party spread across the United States, sales of Tupperware products proliferated, making Tupperware one of the most widely recognized brand names in the United States by the end of the decade.

Despite the success of his company, Tupper reportedly grew restless as the Tupperware empire grew larger and more difficult to control. Frustrated by the media attention focused upon Wise and the expenses incurred by the elaborate system of seller incentives that she created, Tupper abruptly fired her in 1958, subsequently erasing all references to her from advertisements and company literature. Under increasing pressure to incorporate his company and offer public stock to avoid tax liability, Tupper sold the Tupperware company to the owner of the Rexall drugstore chain for $16 million later that year. Rexall retained the business model that had proven successful during the 1950's, and Tupperware parties remained the primary method of marketing Tupperware products through the remainder of the twentieth century. In 1960, Rexall introduced Tupperware products to international audiences, sanctioning the first Tupperware party in the United Kingdom.

Firing Wise and selling his company were but the first of a series of drastic decisions that Tupper made in the late 1950's. Soon afterward, he divorced his wife, relinquished his U.S. citizenship, and purchased a private island in Central America. Tupper soon grew restless in retirement and resumed efforts to invent new products; however, despite his reputation as the inventor of Tupperware, his inventions attracted little interest. He later moved to Costa Rica, where he died in 1983.

TUPPERWARE

Humans have employed various devices and methods throughout history to protect food from decay and consumption by animals, insects, and bacteria. Technological innovations of the early twentieth century, most notably the development of refrigeration technology, had dramatically improved food preservation, yet the metal, glass, and ceramic containers available to households were limited in their ability to preserve food for long periods.

A by-product of petroleum distillation, plastic came into use as a manufacturing material during the early twentieth century as the use of automobiles proliferated in the Western world. The first commercial plastic, Bakelite, was introduced in 1909. However, early plastics were brittle, greasy in texture, and emitted noxious odors, making them unsuitable for use as food containers. Nevertheless, as World War II drew to a close, Earl S. Tupper, eager to develop marketable consumer products from plastic, began work toward refining a plastic product that was durable, pliable, odor-free, and suitable for use in household food containers.

Working with polyethylene waste acquired from the DuPont factory where he worked, Tupper experimented with various chemical formulas and refinement techniques before developing a suitable product in 1946. The end result was the Wonderbowl, which featured a translucent lid with an airtight seal that allowed the user to expel excess air from the inside of the container by pressing down on the lid prior to sealing it (a technique that he dubbed "burping") in order to slow decay by minimizing the exposure of food to air. Tupper produced these bowls, which he eventually renamed Tupperware, in a variety of shapes and sizes and marketed them to wholesale distributors, department stores, and other establishments. However, the bowls sold slowly at first, as many consumers still distrusted plastic and were unconvinced of the benefits of the burping seal. Popularizing the new technology would require the personal touch of the Tupperware party, which allowed consumers to witness firsthand demonstrations of the product.

Other manufacturers soon introduced their own lines of plastic food containers to the consumer market; but the patented burping seal that Tupper had developed distinguished his products from those of his competitors. After the patent for Tupperware expired in 1984, numerous imitation products, many of which featured some variation of the burping seal, flooded the market; yet the Tupperware brand remained the archetypical plastic food container in the minds of Americans, many of whom continued to use "Tupperware" as a generic term to describe all sealable food containers.

IMPACT

The life and work of Tupper exemplified the transition of American society during the mid-twentieth century. A self-taught tinkerer, he realized success as an independent inventor at a time when invention was rapidly becoming the domain of corporate laboratories and major research universities. Tupper was a product of the prewar rural Midwest whose most successful creation exerted a significant impact on life in the growing suburbs of postwar America.

The invention of Tupperware solidified the reputation of Earl Tupper as one of the most influential inventors of the twentieth century. Tupperware joined television, fast food, motels, and interstate highways as symbols of postwar American consumer society and the rapid changes in technology and culture that accompanied it. A simple household product, Tupperware provided a solution to a common and long-standing problem that had assumed a new urgency in the 1950's as young working couples with growing families and increasing demands on their time benefited from ways to preserve leftover food and prepared ingredients more effectively. By developing a new method of refining plastic for practical use, Tupper revolutionized the plastics industry, facilitating the widespread use of plastic products in various household applications. In addition, the business model that he helped create transformed the marketing of consumer products, creating the concept of the home party and influencing other marketing techniques such as infomercials and home shopping channels that emphasized product demonstration and targeted sales pitches.

—*Michael H. Burchett*

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See also: Leo Hendrik Baekeland.

ALAN MATHISON TURING

English mathematician, cryptographer, and logician

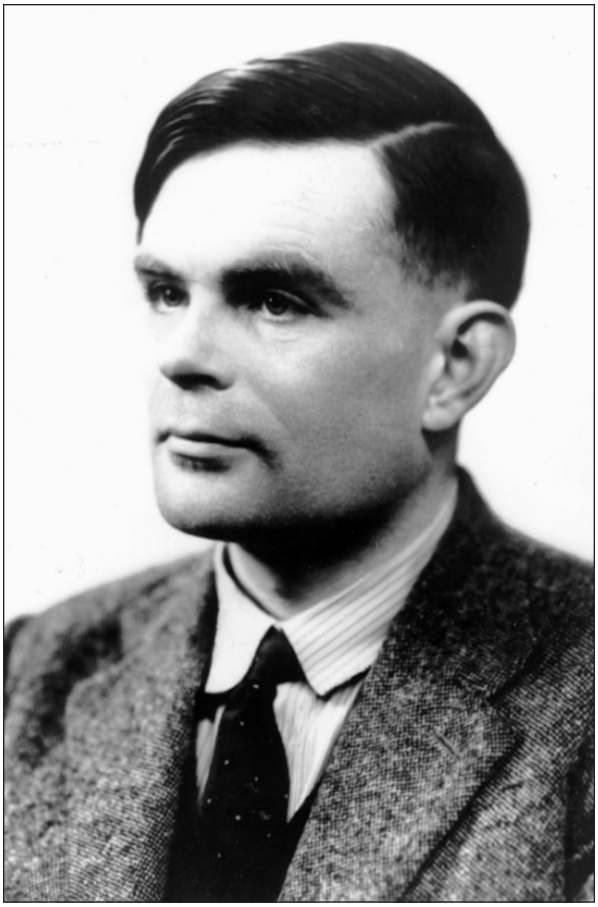
In addition to theoretical work on the possibility of computation, Turing was responsible for laying out some of the basic ideas that enabled early computers to be designed efficiently. In addition, he laid down some of the principles for judging what a computer could do.

Born: June 23, 1912; London, England
Died: June 7, 1954; Wilmslow, Cheshire, England
Primary fields: Computer science; mathematics
Primary inventions: Automatic Computing Engine; Turing test

EARLY LIFE

Alan Mathison Turing, the individual most responsible for the modern computer, was the son of Julius M. Turing and his wife, Ethel Sara. Turing's father was a British civil servant who spent much of his time working in India when Turing was a child. This required either arrangements for keeping Turing and his older brother John in the home of a family willing to look after them or for Turing's mother to spend time away from her husband. While Turing's mother was around, he seemed to be a bright and sociable child, but he lost some of those aspects of personality in her periods of absence. After having gone to a day school until 1921, he was sent to a boarding school where his brother was a student. From there, he proceeded to Sherborne School in 1926, one of the great English private schools designed to prepare its students for Oxford or Cambridge.

At Sherborne, Turing made significant progress in mathematics and science, but he continued to display lit-



Alan Mathison Turing. (Smithsonian Institution)

tle interest in his fellow students, many of whom were more interested in athletics than in academic matters. He developed a close friendship with Christopher Morcom, a student whose academic record was unblemished and who served as a model for Turing. There may also have been a touch of romance in the friendship, and it can be argued that many of Turing's subsequent relationships with men were attempts to recover the friendship with Morcom, who died in 1930. It was typical of Turing's interests that one of the prizes he won as a student at Sherborne was a book on the foundations of quantum mechanics by the Hungarian mathematician John von Neumann.

In 1931, Turing matriculated at King's College, Cambridge, one of the grandest colleges in the university and one with a tradition of mathematical accomplishment. He was already indulging in mathematical research, although some of it was rediscovery of what had already been known. Many students tended to concentrate on the material that would appear on the final examination that they would face at the end of their undergraduate careers, but Turing had a broader range of interests, from statistics to applied mathematics. In particular, he was able to come up with an improvement on one of the results of von Neumann. When he took the Tripos (the final examination in mathematics) in 1934, Turing emerged with a first-class degree and with the offer of a studentship at King's College. From there, he proceeded to a fellowship the next year. At this point, Turing had a more positive view of the future than he had had since starting at Sherborne.

LIFE'S WORK

Turing attended a sequence of lectures on the foundations of mathematics by Cambridge colleague M. H. A. Newman. Newman introduced Turing to the work of the Austrian mathematician Kurt Gödel, who had proved a few years before that there were undecidable statements in arithmetic. Undecidable statements are those that cannot be proven or disproved within the rules of arithmetic, and their existence came as something of a surprise. Some viewed Gödel's result as the refutation of some of the schools of mathematical philosophy that had been most popular earlier in the century.

One of those schools of mathematical philosophy was associated with the name of David Hilbert, long associated with the German university of Göttingen. Hilbert had claimed that mathematics needed to find a procedure that would enable every question to be decided in a finite amount of time (called a "decision procedure"). One of the difficulties in tackling Hilbert's problem was trying to find a way to represent what form a solution would take. Turing came up with a method for tackling Hilbert's problem that enabled him to answer the question of whether every problem is decidable in the negative. He could use some of the ideas in Gödel's work associated with self-reference, but he also came up with the model for computation that underlay the developments in computer science for the rest of the century.

Turing's idea was a simple one. He imagined an infinite tape divided into squares and a machine that would scan one of those squares at a time. The machine would either mark something on the square, erase what was on the square, or just leave the square alone and then move to an adjacent square. The machine's behavior was based on the state in which it was while scanning the square, and it could move from that state into another one as it scanned the next square. This simple and easily imaginable machine became known as a "Turing machine." A Turing machine could be designed to handle any particular problem, provided that it was theoretically possible. Turing's article describing this approach to mathematics (and founding, in the process, the discipline of computer science) was ready for publication in 1936.

That same year, the American logician Alonzo Church at Princeton University produced a different way to show that Hilbert's problem was unsolvable. While it took some time to sort out the connections between Church's and Turing's approach, Turing felt that it would be worthwhile to go to Princeton for a couple of years in order to learn about what was being done there. He received financial support and was able to benefit from the company of many of the world's leading logicians, either as visitors or colleagues there. Among them was von Neumann, with whom Turing also spoke about some of his ideas for the future of computation. Turing had an interest in physically constructing the kind of machine that he had envisaged.

A more immediate concern arose in the form of dealing with the war with Nazi Germany. After Turing returned to Cambridge in 1938, he was recruited for service to the war effort (in advance of the outbreak of war) and became part of the group of code-breakers at an establishment at Bletchley Park determined to unravel German naval codes as created by what was called an Enigma machine. There was a great deal of mathematical talent in that group, but there was also the need for some computing assistance. While the group's ultimate success contributed to the defeat of the Germans, one of the important tools was a machine called the Colossus. It did not have the theoretical features of a computer such as Turing envisaged, but it demonstrated the potential of what technology could offer.

At war's end, Turing became employed by the National Physical Laboratory. Within a couple of months, he had written a proposal for an "Automatic Computing Engine" (ACE), based on his theoretical and practical understanding of what could be accomplished. If the machine had been built at the time, it would have been the first stored-program computer in the world, but all sorts of practical difficulties intervened. Turing had never been the most diplomatic of researchers, and it required the help of others to elicit the funds to make ACE, even in pilot form. By the time it was finished in 1950, Turing had gone on to work at the University of Manchester, also a center for the design and construction of computers. He also took up the application of mathematics to understanding biological development.

Turing had not let his eminence interfere with his social life, and this had dire consequences. Homosexuality, even between consenting adults, was a criminal offense in the England of the 1950's, and Turing found himself arrested in 1951 and convicted in March, 1952. The sentence involved his taking a course of hormone therapy, whose emotional effects were not fully explored. Two years later, Turing died of eating an apple that had been

THE AUTOMATIC COMPUTING ENGINE

Calculators capable of carrying out arithmetic operations had been designed long before Alan Mathison Turing. One of the innovations of the work of Charles Babbage in the nineteenth century had been the attempt to construct a machine that could go beyond simple calculation, but there had still been limits as to what scientists believed a machine could do. Turing, by virtue of the formalism he had discovered in the 1930's, conceived of a machine that could do anything if it was given the appropriate program. The problem that he faced in his proposal for the "Automatic Computing Engine" (ACE) was realizing this theoretical model in practical form.

By the end of the World War II, Turing had learned enough about engineering to provide the specifications for his machine rather than leaving this work to others. Turing favored ingenuity in programming over the construction of more complicated machinery. Rather than building a component for doing addition, Turing would write a series of instructions that would carry out the addition on the standard circuitry. Turing used a delay line (a contribution from others that he acknowledged) for storage of information. The delay line consisted of a tube of mercury in which there would be an acoustic delay in transmitting pulses. This provided for indefinite storage of information, an essential step for writing programs.

The crucial notion of optimum coding involved having each instruction give the address for the next instruction. This avoided the issue of latency, which had limited the number of executions that could be instructed in a cycle. As simulations conducted long after Turing's death indicate, the Pilot ACE (the first version of the proposed machine to be constructed) was faster than the other British computers of the time. It had among its descendants the DEUCE machines, constructed between 1955 and 1962. By the end of that period, the physical machine that Turing built had lost its applicability, but Turing machines have not.

coated with cyanide. The usual explanation is that he committed suicide as a result of depression.

IMPACT

The Automatic Computing Engine designed by Turing was an improvement on any of the other machinery available at that time. It remained an important feature of the computing landscape for the rest of the decade. After the difficulties involved in getting a pilot version built, the results were enough to convince industry that the features of the machine deserved to be more generally adopted.

Beyond the specific machine that Turing designed, his vision of computing was the inspiration for many in both machine design and theoretical computer science. Turing foresaw that, as computers became more powerful and widely used, issues would arise about whether a computer could "think." For example, it was tempting to argue that a chess-playing computer would be a "thinking machine"; however, it could be argued that such a machine showed instead that chess playing did not require thinking. Turing proposed a simple test to determine whether a computer could "think": If someone interacting with the computer was unable to tell whether it was a machine or not, then it could be considered intelligent. As computers have increased in the number of tasks they can perform, the Turing test remains a way of addressing the issue of machine intelligence.

The Turing machine served as a theoretical basis for generations of computers. By the end of the twentieth century, there were a couple of theoretical alternatives to consider. Nondeterministic Turing machines, for example, allowed for a randomizing device capable of producing a solution faster than a traditional Turing machine, which was used as the means for measuring the complexity of a problem. Theoretical "quantum computers" were also introduced, again with the possibility of solving problems faster than a standard machine. These faster machines have not been built, but the fact that the Turing model is still being compared with them is testament to the lasting influence of Turing's work.

—Thomas Drucker

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See also: John Vincent Atanasoff; Charles Babbage; John Bardeen; Clifford Berry; Nolan K. Bushnell; John Presper Eckert; Ted Hoff; Konrad Zuse.

MARK TWAIN

American author

Although he earned a great deal of money from writing the books that made him famous, such as Tom Sawyer *and* Adventures of Huckleberry Finn, *Twain always aspired to greater wealth through business ventures and investments in new technologies. He greatly admired inventors, who figure prominently in his writings, and patented inventions of his own.*

Born: November 30, 1835; Florida, Missouri
Died: April 21, 1910; Redding, Connecticut
Also known as: Samuel Langhorne Clemens (birth name)
Primary field: Printing
Primary invention: Self-pasting scrapbook

EARLY LIFE

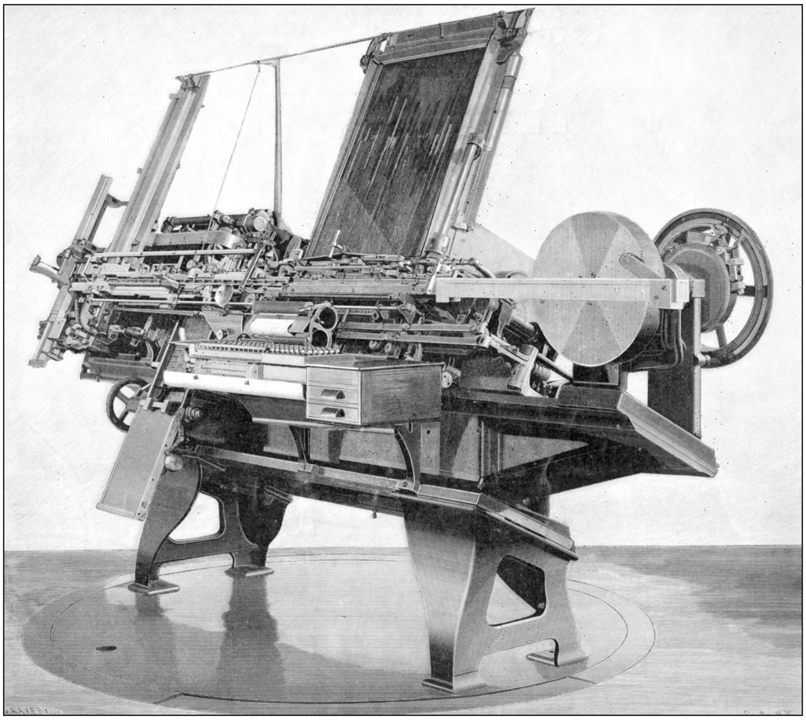
Born Samuel Langhorne Clemens in the northeastern Missouri village of Florida, Mark Twain grew up in nearby Hannibal, a port town on the Mississippi River. His formal education ended there when he was eleven, but around that same time he was apprenticed to a local newspaper publisher. Thus, like many other nineteenth century American writers, he began his career as a printer. Working on newspapers fostered a lifelong habit of reading that eventually made him one of the great autodidacts of his time. Science, technology, and history were his favorite subjects, and he grew up acutely aware of the changes brought by the Industrial Revolution.

In 1853, before turning eighteen, Twain left Hannibal permanently. Working as an itinerant printer, he made his way to New York City, where he thrilled to the marvels of a great world's fair. He also spent time working in Philadelphia, the home of America's first great inventor, Benjamin Franklin, whose career would always fascinate him. After returning to the Midwest, he continued working as a printer, mainly for his older brother, Orion Clemens, who had relocated to southern Iowa.

Twain's life turned in a radically new direction in 1857. Early that year, he went to New Orleans, where he persuaded a veteran steamboat pilot to take him on as an apprentice. Over the next four years—first as an apprentice and then as a licensed pilot—he steered steamboats between St. Louis and New Orleans. He loved the freedom and prestige of his work and might have remained on the river indefinitely. However, the outbreak of the Civil War in early 1861 ended commercial traffic on the Lower Mississippi. While other steamboatmen joined the Union and Confederate navies, Twain went west with his brother Orion, whom President Abraham Lincoln had appointed secretary of the new Nevada Territory.

LIFE'S WORK

After crossing the plains with his brother, Twain took up prospecting in western Nevada. A year of unremunerative mining work spoiled his dreams of easy riches, so he became a beat reporter for the *Virginia City Territorial Enterprise*. In early 1863, he adopted the pen name "Mark Twain" as he built a reputation as a humorous



With its 18,000 separate parts, the Paige compositor was far too complicated to provide reliable service in newspaper printing offices. (*Scientific American*, March 9, 1901)

The Paige Compositor

Almost certainly the most complex typesetting machine ever made, James W. Paige's two-and-one-half-ton compositor had more than 18,000 parts. Not surprisingly, it also generated some of the most complicated paperwork in U.S. patent history. Paige's 1887 patent application alone contained 275 sheets of drawings and 123 pages of technical specifications.

Paige's machine could handle only one size of metal type (a significant limitation), which was stored in nearly vertical channels holding two hundred pieces each. A human operator used the machine's keyboard to arrange the type in text: Each keystroke made a plunger push a piece of type from its gravity-fed channel into a horizontal raceway. As each word was completed, the operator pressed another key to move it to a raceway in which full lines were assembled. Each time the machine signaled that a row was filled, the operator pressed another key launching the machine's delicate justification operation, which measured the row and inserted spaces to fill out the line before moving it to a galley tray. While all these operations were proceeding, dead matter deposited beneath the machine was automatically sorted and moved up channels on the machine's backside to be distributed for reuse.

The machine's sheer complexity and particularly its large number of moving parts, which turned on eight hundred separate shaft bearings, combined with the delicacy of its individual operations to make it jam frequently. Paige never got it to operate for sustained periods without breaking down. When his machine was running smoothly, it set type faster than Ottmar Mergenthaler's Linotype machine, but the latter proved more reliable because it used significantly fewer moving parts. Instead of emulating human typesetting steps that required handling individual metal pieces for each character and space, the Linotype machine used molds of individual characters to make matrices of entire lines into which hot lead was poured. As the lead cooled into firm metal bars, the molds returned to their original places without leaving the machine. Later, after the lead bars were used for printing, they were simply melted down and poured back into the machine, so there was no need to distribute dead matter.

writer. The following year, he relocated to San Francisco, where he worked for a local newspaper and continued writing humorous sketches. Reports he wrote from Hawaii in 1866 enhanced his West Coast reputation, but national fame arrived a year later, when he went to Europe and the Middle East on the cruise ship *Quaker City* and wrote dozens of humorous letters that were printed in newspapers throughout the United States. Afterward, he capitalized on his new celebrity by publishing *The Innocents Abroad* (1869), an account of his trip that became the best-selling American travel book of the nineteenth century. He soon followed it with *Roughing It* (1872), an almost equally popular book about his years in the West.

The large sums that Twain made from his early travel books set the standards by which he measured the success of all his future books. Meanwhile, he got married in 1870 and settled in Buffalo, New York. After a brief stint as the part owner and coeditor of the *Buffalo Express*, he realized that his true calling was that of a writer. In 1871, he moved to Hartford, Connecticut, which remained his primary home for two decades. Those years were his most productive period as a writer, and he earned worldwide fame with such books as *The Adventures of Tom Sawyer* (1876), *A Tramp Abroad* (1880), *Life on the Mississippi* (1883), *Adventures of Huckleberry Finn* (1884), and *A Connecticut Yankee in King Arthur's Court* (1889). Twain probably netted more from his books and lecture tours than any other writer of his time, and his wife inherited a substantial fortune. Nevertheless, fear of returning to his childhood poverty continually drove him to look for more ways to increase his income.

Twain's experience as a printer, steamboatman, and miner helped increase his interest in new technologies. During the mid-1870's, he became one of the first writers to use a typewriter. In 1877, his Hartford home became one of the first private residences in the world to have a telephone installed. He enjoyed associating with scientists and inventors and had memorable meetings with Nikola Tesla and Thomas Alva Edison. The latter recorded Twain's voice on wax cylinders (later lost in a fire) in 1888. Twain's writings make it clear that he regarded the nineteenth century as the period of the greatest technological advancement in human history and esteemed the inventors who made the advances possible. Inventors figure prominently in his novels *A Connecticut Yankee in King Arthur's Court*, *The American Claimant* (1892), and *Tom Sawyer Abroad* (1894), and he wrote numerous essays on inventors and technology.

Twain's interest in technology made it natural for him to invest in new inventions and even to dabble in inventing gadgets himself. In 1872, for example, he hit on the idea of making scrapbooks with preprinted glue strips on pages that needed only to be dampened with water. After patenting the idea the following year, he arranged with Dan Slote, a friend he had made during his 1867 trip to Europe, to manufacture the books. Slote's company eventually produced more than thirty different sizes and specialized models of "Mark Twain's Patent Self-Pasting Scrap Book." The books sold well through the 1870's.

Other inventions that Twain patented during this period included a bed clamp and a self-adjusting garter, neither of which he ever marketed. In 1885, he patented a history board game that he called "Mark Twain's Memory Builder," based on a game he played with his daughters. He had several models of the game manufactured for test-marketing in 1891, but it was too complicated to catch on with the pubic, and he gave up on it.

Twain's self-pasting scrapbook was his only profitable invention, but he invested a great deal of money backing other people's inventions. However, his fascination with impressive novelties often blinded him to practical difficulties, causing him to make poor investment choices. For example, he lost about $50,000 backing a process for making engraved printing plates called Kaolatype, whose patent he bought in 1880. With the misguided optimism that typically characterized his investments, he predicted that Kaolatype would revolutionize engraving in the printing industry and formed a company with himself as president and principal stockholder. Soon, however, Kaolatype was made obsolete by cheaper photographic engraving processes that produced better results.

As Twain was giving up on Kaolatype, he found an even more promising investment opportunity—an automatic typesetting machine that James W. Paige (1842-1917), a mechanic working in Hartford's Colt Arms Factory, had begun developing around 1873. Paige was addressing a need dear to Twain's heart. After Johann Gutenberg had invented movable type during the fifteenth century, typesetting had seen few improvements up to the time Twain himself worked as a printer. Rotary presses and other nineteenth century innovations greatly improved the speed of printing, but typesetting remained a bottleneck crying out for automation. Paige's machine promised to meet that need, and Twain was awed by its mechanical brilliance.

For four centuries, compositors had used only their hands to set type, by painstakingly selecting individual metal characters from boxes and arranging them, row by row, on galley trays. After type was used for printing, it was sorted and "distributed" to the original boxes. A keyboard-operated machine that used individual pieces of metal type, Paige's machine automated each human typesetting step, making it possible for a single operator to set type as much as six to ten times faster than could be done by hand.

Twain estimated that thousands of newspapers would buy Paige's machine, and he may have invested as much as $200,000 in the machine between 1880 and 1894, by which time he owned a half-interest. The unpleasant reality was that not a single machine was ever sold. The machine was a true marvel of engineering but was doomed by a fatal flaw: It had too many moving parts to stand up to heavy use over time. Its inventor was a perfectionist who toiled ceaselessly to improve its performance but never quite succeeded. He repeatedly failed to live up to his promises to complete the machine on schedule but used his extraordinary powers of verbal persuasion to string Twain along for years.

The end came in 1894, when Paige finally had a working model ready for testing in a Chicago newspaper office. By then, however, his machine had already been made obsolete by Ottmar Mergenthaler's slower but more reliable Linotype machines. On the basis of the machine's Chicago trial, Twain's friend and financial adviser, Henry Huttleston Rogers, a Standard Oil executive, declared that the machine had no commercial potential. Twain's investments were a complete loss that helped drive his publishing company to brankruptcy. Paige himself later died in a poorhouse in Chicago.

Twain's mistake was allowing himself to become so beguiled by the brilliance of Paige's engineering feat that he failed to see the machine's fundamental flaw. It was not the last time he made that mistake. While living in Vienna in 1898, he befriended a brilliant inventor named Jan Szczepanik, whom he called the "Austrian Edison," who had invented a photographic process for transferring patterns to woven textiles. Despite having only recently recovered from the huge financial losses of his investments in the Paige compositor, Twain was eager to invest in Szczepanik's new invention. Wiser counsel eventually prevailed, however, when his friend Rogers investigated the economics of the weaving industry and concluded that Szczepanik's marvelous invention had no valuable commercial applications.

IMPACT

As a writer, Twain was one of the most influential innovators in American literary history, particularly in narrative technique. He probably had a higher regard for technology than for literature, but his contributions to technology were those of a gadgeteer, not a true inventor. His material inventions were mostly novelties that are remembered now only because he invented them. His closest brush with greatness in technological innovations was his connection with the Paige compositor, which he sincerely believed would revolutionize the publishing industry. Had Paige managed to get the machine working reliably by the mid-1880's, Twain's grandiose dreams for it might have come true. However, by the time it was tested in a newspaper office in 1894, Mergenthaler's more reliable Linotype machines were too well established for it to compete, and they dominated typesetting over the next century. It is perhaps ironic that Mark Twain, whose own inventions were simple gadgets, should blow his fortune on a machine whose greatest failing was its complexity.

—*R. Kent Rasmussen*

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See also: Thomas Alva Edison; Johann Gutenberg; Bill Lear; Ottmar Mergenthaler; Nikola Tesla.

JOHN TYNDALL

Irish physicist

A promoter of science in Victorian-era England, Tyndall laid the groundwork for later scientific developments in atmospheric sciences. He developed the idea of an "atmospheric envelope," which suggested that water vapor and carbon dioxide in Earth's atmosphere retain heat radiated by the Sun (the "greenhouse effect").

Born: August 2, 1820; Leighlinbridge, County Carlow, Ireland
Died: December 4, 1893; Hindhead, Surrey, England
Primary field: Physics
Primary invention: Fireman's respirator

EARLY LIFE

Born in Leighlinbridge, County Carlow, Ireland, the son of a local police officer and small landowner, John Tyndall attended a common school in County Carlow. He joined the mapmaking Irish Ordnance Survey as a draftsman at age nineteen. His surveying experience later took him to England as an employee of the English Ordnance Survey beginning in 1842, after he was selected as one of the best draftsmen in his department. While there, Tyndall attended lectures at the Preston Mechanics' Institute. His surveying work extended the British national network of railways during the 1840's. By 1844, Tyndall was working as a railway engineer.

Tyndall played many roles during his career, including surveyor, draftsman, surveyor, professor of physics, mathematician, mountaineer, geologist, atmospheric scientist, author, and popular public lecturer. He left surveying in 1847 to teach mathematics at Queenwood College, in Hampshire, but soon enrolled at Germany's Marburg University, where he studied science between 1848 and 1851 with a colleague, Edward Frankland, and the mathematician Thomas Hirst. Tyndall studied under Professor Robert Wilhelm Bunsen, and his dissertation was on screw surfaces. He completed three years' worth of graduate work in two.

Tyndall married Louisa Hamilton, a daughter of Lord Claud Hamilton, in 1876. The next year, the new couple built a small cottage at Belalp in the Swiss Alps above the Rhone Valley. Eight years later, they also built a home at Hindhead, near Haslemere in Surrey, England.

LIFE'S WORK

A prolific lecturer and writer about many scientific subjects, Tyndall was the first person to calculate quantitative, spectroscopic measurements describing ways in which water vapor and carbon dioxide trap thermal radiation. Tyndall also theorized that Earth's climate could warm or cool in proportion to the amount of carbon dioxide and other trace gases in the atmosphere. As a student of glacial movement, he also speculated in 1861 that a decline in the atmosphere's carbon dioxide levels might have played an important role in the onset of ice ages. Tyndall also invented several precision instruments to measure phenomena about which he theorized. During his working life, he published at least sixteen books and 145 scientific papers.

Tyndall's first scientific work, between 1850 and 1855, involved experiments on magnetism and diamagnetic polarity, undertaken while he was teaching at Queenwood College. This work brought him to the attention of well-known scientists, and he was elected as a fellow of the Royal Society in June, 1852.

While he studied glaciers, Tyndall also trained himself as a world-class mountain climber. In 1861, he became the first person to reach the summit of the Weisshorn in the Swiss Alps. Tyndall nearly reached the top of the Matterhorn in 1864, failing by only a few hundred feet because of a storm. A year later, Edward Whymper reached that goal. The penultimate peak of the Matterhorn was named "Pic Tyndall" for him.

In 1862, Tyndall succeeded the popular teacher Michael Faraday, giving popular physics lectures at London's Royal Institution (which he later directed), as he became one of the best-known scientists of the Victorian era. He had first met Faraday in 1850, and he later celebrated the physicist in a book, *Faraday as a Discoverer*, published in 1868. Tyndall also was a member of the X Club, composed of renowned scientists, along with other

THE FIREMAN'S RESPIRATOR

Masks to protect firefighters and others against smoke and toxic fumes were invented in the middle of the nineteenth century. Before that time, most firefighters had used primitive bags over their heads. As early as the sixteenth century, Leonardo da Vinci wrote that a woven cloth dipped in water could protect sailors from a toxic fumes. One of John Tyndall's most notable inventions was the fireman's respirator, one of the best-known early gas masks, introduced in 1871. The technology and design of Tyndall's respirator improved at least two earlier designs by other inventors. In 1847, Lewis Haslett of Louisville, Kentucky, designed an air-purifying mask that filtered contaminated air with moist wool or other porous substances. He gave it the name "Inhaler or Lung Protector." In 1854, chemist John Stenhouse of Scotland developed the "Stenhouse Gas Mask," using powdered charcoal to remove toxic gases.

Some chemical factories in the United Kingdom used Tyndall's gas mask. Tyndall's respirator took advantage of Stenhouse's technology and combined it with cotton saturated with glycerin and lime. The lime absorbed carbonic acid (common in the combustion of fires), and the glycerin helped to catch particles in smoke. The July, 1875, issue of *Manufacturer and Builder* described Tyndall's device as a "fireman's hood" containing a valve chamber and filtering tube roughly four inches long that attached from the outside with a screw. The respirator used a wooden mouthpiece.

Tyndall promoted his respirator by declaring that a firefighter using it could survive a half hour in the most noxious fumes. Without the protection offered by his mask, the same person would have been incapacitated in less than a minute, Tyndall said. Tyndall exhibited his respirator at a meeting of the Royal Society in London in 1874; he also described its origins and workings in *Proceedings of the Royal Society*.

Tyndall faced considerable competition. Three years after he exhibited his invention, Samuel Barton of London invented a device that used a face covering of rubber and metal, a head harness, and glass eyepieces. Barton's filtering technology was substantially the same as Tyndall's, however. Later designs by other inventors refined both the design and filtering technology of the masks.

notables, including Thomas Henry Huxley and Herbert Spencer. By this time, the nature of atmospheric gases had become Tyndall's major scientific inquiry.

Tyndall also was a tireless public intellectual, a public advocate of science who wrote for a number of popular magazines in addition to his popular lectures. He toured the United States during 1872 and 1873, drawing large audiences. Tyndall earned several thousand dollars from his American tour that was donated to scientific work in the United States. He also donated money for a new technical school in County Carlow.

During 1874, Tyndall gave a speech, now known as the "Belfast Address," at the British Association for the Advancement of Science's annual meeting. This speech became a cardinal citation in arguments that the rational, materialist methods of scientific inquiry (usually called "natural law," as opposed to church law) were superior to religious or other explanations for phenomena. He addressed the brewing controversy over Charles Darwin's theories of evolution that continue to incite political controversy today.

In his later years, Tyndall suffered from insomnia to a point that imperiled his health. On December 4, 1893, at Hindhead, Tyndall died after Louisa accidentally gave him an overdose of chloral hydrate (which he had been being used to induce sleep). As he died, Tyndall moaned that the drug was killing him. Louisa searched frantically (and fruitlessly) for an antidote. She summoned a doctor who gave Tyndall an ineffective emetic as he died.

Louisa spent the rest of her life looking after Tyndall's reputation, including clashes with several commissioned biographers whose work did not meet her expectations. Having chosen Leonard Huxley (and later A. S. Eve and C. H. Creasey) to write John's biography, Louisa refused them access, for unstated reasons, to some of his private papers. She also purged her own diaries of material on her relationship with him and otherwise made the compilation of an accurate life story difficult. The parts of these diaries that survived her editing have been archived in the Royal Institution of London.

IMPACT

Tyndall became very well known in his time, in part because of his writings, which ranged from scientific papers describing his discoveries to popular essays on scientific subjects, as well as religion, literature, and travel, including his passion for mountaineering in the Alps. Tyndall went out of his way to present science to children. He received five honorary doctorates and was a member of thirty-five scientific societies.

Tyndall's own work is important as well, because he laid the groundwork for later scientific developments in atmospheric sciences that provide the basic intellectual infrastructure for studies of Earth's climatic heating and cooling cycles. His work on purification led to methods of sterilization for liquid water and other liquids that involve heating to the boiling point. His work on sterilization also became central to the practice of medicine.

Tyndall also found ways to filter air so that it was "optically pure," containing very few microorganisms, for experimental purposes. His "pure air" prevented most putrefaction, or decay. Studies of this type of air were used by other scientists to refine Louis Pasteur's germ theory of disease. Tyndall refined his pure air many times, further reducing its impurities. He is also believed to have been the first scientist to measure urban pollution, using samples of his own urine to measure accumulation of various toxins (which caused the urine to putrefy).

Tyndall also pioneered methods to monitor London's air quality at a time when the city was prone to noxious, sometimes deadly, smogs that combined natural, stagnant fog with coal smoke. He was also the first to show that ozone is a cluster of three oxygen atoms. Before his discovery, many scientists believed that ozone was a hydrogen compound.

Tyndall invented a fireman's respirator, a hood that filtered smoke and gas. He was the first person to characterize scientifically the scattering of light by dust and large molecules in the air, a process that became known as the "Tyndall effect." His experiments also helped explain why the sky is blue (from Rayleigh scattering of sunlight).

—*Bruce E. Johansen*

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See also: Robert Wilhelm Bunsen; Michael Faraday; Louis Pasteur.

LEWIS URRY

Canadian chemical engineer

Urry's development of the alkaline battery made it possible to significantly extend the effective lifetime of batteries used in personal and household items ranging from commonplace flashlights and smoke detectors to complicated electronic devices. By the end of Urry's active career, his original contribution had been carried forward by researchers who developed the extremely sophisticated batteries that power not only modern portable electronic devices but also critical medical devices such as pacemakers.

Born: January 29, 1927; Pontypool, Ontario, Canada
Died: October 19, 2004; North Olmsted, Ohio
Also known as: Lewis Frederick Urry (full name)
Primary fields: Chemistry; electronics and electrical engineering
Primary invention: Alkaline battery

EARLY LIFE

Lewis Frederick Urry was born in 1927 in Pontypool, Ontario, Canada. After serving in the Canadian army between 1946 and 1949, he studied at the University of Toronto, receiving a degree in chemical engineering in 1950. His first employment was with the Eveready Battery Company, the firm that had a very long history going back to the development of battery cells for use mainly in household flashlights. While still a young man of twenty-eight, Urry moved in 1955 to the Eveready main research laboratory in Parma, Ohio. His assigned task, which yielded results by the end of the decade, was to find a way to lengthen the life span of what was then the commercially dominant zinc-carbon battery.

LIFE'S WORK

When Urry moved to Eveready's laboratory in Ohio, a number of researchers working for battery manufacturing companies had already begun investigating the possibility of extending the effective life of common household batteries using zinc-carbon electrodes and acidic components as electrolytes. Batteries in this category were called galvanic cell batteries. Although an entirely different category of battery—dominated by the technology used to produce automobile batteries—involved combinations of chemical components that lent themselves to recharging, the market sector that interested Eveready covered mainly portable electrical devices. The limitations of size and weight precluded any possibility that the technology of automobile batteries would attract Urry's attention.

In retrospect, the essentials of the challenge Urry faced would appear rather simple to a modern student of chemistry familiar with the process of ionization. Ionization occurs when electrons contained in an atom (or a molecule composed of diverse atoms) absorb at the time of a chemical reaction a sufficient amount of energy (called the ionization potential) to break away from the normal electric potential system that binds them in atomic orbit. When electrons break loose, what remain are referred to by chemists as (variously charged) ions. Electrons are the bearers of energy known as electricity. Battery technology involves containing and directing the movement of electrons released through chemically induced ionization. It was Urry who introduced the idea that, by using an alkaline-based electrolyte together with manganese dioxide and solid (later powdered) zinc in what was essentially the same structural makeup as batteries already being produced, one could obtain a higher level of electron emission in the ionization process than was produced by acid-based components.

In 1980, Eveready decided to adopt the name Energizer as the new label, for marketing the (by then improved) alkaline battery originally developed by Urry. The Eveready label was retained for marketing standard carbon-zinc batteries that, because of their lower price, continued to supply a significant portion of the consumer demand market.

Over time, and indeed right up to Urry's departure from the active scene that he had originally pioneered with Eveready, developing technology made it possible to market an entire line of Energizer batteries offering significantly different performance specifications. Two models beyond the widely used Energizer Max alkaline battery (essentially designed for common household and portable electronics), the very lightweight Advanced Lithium and Ultimate Lithium Energizer batteries would carve out somewhat specialized segments of the consumer market. Both lithium-based batteries not only proved to be more efficient for use in technologically more complex systems demanding higher levels of electrical current but also could promise consumers longer storage life, ranging between ten and fifteen years.

Although such qualitative differences came to characterize the market for alkaline-based batteries, impressive quantitative developments were recorded in another

ALKALINE BATTERIES

Understanding the basic principles of electrical current helps one to understand the workings of even the most commonplace flashlight battery. All batteries have a positive and a negative terminal. In large batteries such as those used in automobiles, the terminals are easily visible as lead posts, or poles; in most common batteries, the terminals are at opposite ends. In simple terms, electrical current within a battery occurs when electrons (which are by definition negatively charged) concentrated around the negative terminal flow via a conducting link (something as simple as a wire) toward the attractive force in the positive terminal. The energy of this electron flow, or electricity, can be tapped by connecting a "load," be it a light bulb or a motor, to the path of flowing electrons.

The supply of electrons in the battery comes from the chemical process of ionization described in basic chemistry texts. Once this process is set in motion—and if a wire connects the two terminals—the flow of electrons starts. Without a connection, no flow occurs because no chemical reaction has been set off. This helps explain why batteries have a surprisingly long shelf life.

On the other hand, very concentrated or rapid flow of electrons between terminals (measured in terms of internal resistance) can have the effect of wearing out the battery. Inventors of the earliest batteries devised the "voltaic pile" as a means of controlling internal resistance. In 1800, Alessandro Volta's first battery incorporated alternating "sandwiches" of zinc and silver (one metal on one end acting as the negative pole, the other as the positive pole) separated by paper layers. In modern terms, this voltaic pile served as an electrolyte in the overall process of creating and controlling electrical current inside a battery.

Experiments over time with various metals and electrolyte components (creating conditions for different types of chemical reactions and different levels of voltage) led to the development of a variety of different batteries by the late twentieth century. Notable among these were Energizer's Advanced Lithium battery and titanium batteries offered by a number of commercial producers.

Lewis Urry's own improvements over previously common zinc-carbon batteries using an acidic electrolyte involved the use of zinc and manganese dioxide with an alkaline electrolyte (typically potassium hydroxide). The quantity of electrical current produced by this combination (depending on size, usually indicated by A, AA, or AAA categories for smaller batteries, or C and D for larger models) is only one factor for evaluating the alkaline battery's performance. Longevity—which can be three to five times that of "common" batteries—catapulted the alkaline battery into the top commercially competitive position soon after its introduction in the 1960's.

sphere: battery longevity. Even though consumers were impressed in the 1960's by battery longevity, by the end of the twentieth century "ordinary" but technologically improved alkaline batteries lasted up to forty times as long as the earliest Energizer batteries.

Despite the modesty that surrounded his person and his work by the time of his death in 2004, Urry was able to consider himself a first-generation contributor to the continuously expanding technology of battery cell technology. Several products of the next generation—rechargeable batteries based first on nickel-cadmium and later more efficient nickel-metal-hydride, zinc-air, and lithium-ion components (the latter essential to the laptop computer and cell phone industries)—were being patented and commercialized by inventors whose work owed much to Urry's pioneer discoveries. Patients requiring pacemaker technology to monitor the proper functioning of their hearts owed the very security of their lives to the lithium-iodide battery—another generational product stemming from Urry's pioneer invention.

IMPACT

Although Urry's development of the alkaline battery did not represent what one might call a striking technological breakthrough (since a wide variety of different types of batteries had been in use for several generations, and many would remain on the market alongside the alkaline battery), it certainly had a major impact on the commercial marketing of batteries used for everyday purposes. Because of their longer service life, and despite their visibly higher initial purchase price, alkaline batteries attracted buyers who wanted to avoid recurring unpredictability (and therefore a certain degree of risk, depending on the nature of the battery-powered device being used) associated with "conventional" zinc-carbon batteries.

Success in market competition depends not only on the proven technical qualities of a given product but also on the attractive power of advertisements. Potential Energizer consumers came to recognize the company's slogans during the mid- to late 1980's: "It's supercharged!"

in 1986 and, beginning in 1989, "It keeps going and going and going"—the company's classic slogan that accompanied the now familiar figure of the Energizer Bunny, who "beat the drum" in energetic support of the superior Energizer battery. As the popular demand for long-life batteries expanded, Energizer, alongside the competitor product developed by Duracell, essentially dominated the consumer market. Energizer's use of a battery-driven bunny was inspired from a similar rabbit figure adopted earlier by Duracell for advertisements in Great Britain. In stages, alkaline batteries became commonplace items on display in drugstores, supermarkets, and convenience stores all over the world. Although the alkaline battery stands out as the most widely known of Urry's inventions, his name appears on the original certificates of more than fifty patents.

—*Byron Cannon*

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See also: Michael Faraday; Wilson Greatbatch; Alessandro Volta.

JACQUES DE VAUCANSON

French mechanical engineer

Vaucanson made significant contributions in the automation of manufacturing. He was responsible for the invention of a number of machine tools as well as tool-making machinery. His creation of the punch card has played an important role in computer technology, and his work with automata has been influential in the field of medicine.

Born: February 24, 1709; Grenoble, France
Died: November 21, 1782; Paris, France
Primary fields: Manufacturing; mechanical engineering
Primary inventions: The Flute Player (automaton); Digesting Duck (automaton); automated loom

EARLY LIFE

Jacques de Vaucanson (voh-kahn-sohn) was born in Grenoble, France, on February 24, 1709. He was the tenth child born into his family; his father was a glove maker. From 1717 to 1721, Vaucanson attended the Jesuit College of Juilly in Grenoble and then that of the Oratorians. He was fascinated by science, particularly mechanisms, and began repairing clocks and watches. He was greatly influenced by the works of René Descartes.

Vaucanson was also drawn to a career in the Roman Catholic Church, joining the Order of the Minims at Lyon as a novice. Unfortunately, his ecclesiastical vocation and his penchant for science and mechanisms were scarcely compatible. During this time, he became interested in automata—self-operating, lifelike machines. When he showed some automata that he had made to a visiting dignitary of the order, he was ordered to destroy them and expelled from the Minims. He went to Paris, where he obtained the protection of the banker Samuel Bernard. From 1728 to 1731, he studied anatomy, physics, mechanics, and music. Vaucanson was fascinated by human anatomy and tried to create a mechanical model that replicated the primary functions of the human body. François Quesnay and Claude-Nicolas Le Cat, surgeons who were exploring the possibility of creating artificial devices to aid in the treatment of illness, encouraged him in his work, but, at that time, Vaucanson had little success with his models.

LIFE'S WORK

In spite of the problems he encountered in his early attempt to make an automaton that performed the various functions of the human body, Vaucanson continued to investigate and work on the creation of mechanical models. Inspired by his interest in music, he worked on The Flute Player automaton beginning in the early 1730's, and this became his first successful robot. In 1738, he presented his creation to the Académie des Sciences, where it was well received and recognized as being more than a mere toy because of its lifelike qualities. The life-size Flute Player, dressed as a shepherd and seated on a rock, fascinated the public with its ability to play songs. Vaucanson exhibited his automaton at the fair of Saint Germain and then at the Hôtel de Longueville.

In 1738, Vaucanson constructed two more automata. One was another flute player that also played the tambourine (The Tambourine Player). This second flute player resembled the first; it was life-sized and dressed as a shepherd, but its ability to play instruments was more sophisticated. The first automaton's ability to play the instrument depended entirely on the movement of its fin-

Jacques de Vaucanson. (The Granger Collection, New York)

VAUCANSON'S DIGESTING DUCK

After successfully creating his musical automata, The Flute Player and The Tambourine Player, Jacques de Vaucanson invented his most famous automaton, a lifelike duck that was capable of standing, sitting, swimming, flapping its wings, eating, digesting, and defecating. The Digesting Duck was exhibited with the two musicians in many cities in France, including Paris, Rennes, Angers, and Tours. The duck was an exact reproduction of a real duck; Vaucanson even carefully recreated the entire bone structure of the wings. The wings contained more than four hundred moving parts and were operated by a complex set of levers.

The duck automaton was first exhibited in 1738. Mounted on a pedestal in which the complex mechanism of the duck was visible to the observer, the duck stretched its neck out to receive a grain of corn, which it appeared to swallow, digest, and defecate. It was later discovered that the duck did not actually digest the corn; the material excreted was a mashed grain of corn placed in a small compartment in the duck's anus.

Nevertheless, the duck was a very important advance in the creation of automata. Vaucanson used an extremely complex combination of weights and cams and a system of levers to make his duck function. For the duck's intestines, he used rubber tubing, and he invented a machine to produce the tubing. The duck was extremely popular throughout Europe. Unfortunately, all of Vaucanson's automata have since disappeared. It is believed that the musicians were destroyed during the French Revolution; the fate of the duck is unknown. A replica of the duck made by Frédéric Vidoni is on display at Le Musée des Automates de Grenoble.

The technology that Vaucanson developed and used in his duck and other automata changed attitudes toward automata, which up to that time had been appreciated for their novelty but considered primarily as toys. Vaucanson's creations earned automata a place in the field of serious scientific research, especially in surgical medicine, as well as advancing the technology of automation in manufacturing.

gers and lips and mechanical control of the air supply. Another instrument could be substituted for the flute. The second robot actually interacted with the musical instrument. For the proper notes to play, the movements of the tongue had to be precise and the fingers of the automaton had to cover the holes in the flute, requiring more complex finger movements. Vaucanson was very proud of his creation and credited it with playing better than a human flutist. His most famous and most complex automaton, the Digesting Duck, was exhibited that same year. The automaton could flap its wings, eat grain, and even defecate feces. The mechanism that made the duck function was left visible so that spectators could appreciate the complexity of the mechanical construction.

Returning to his interest in the functioning of the human body, Vaucanson attempted to build an automaton that possessed an interior mechanism recreating the human system of blood circulation. He did not finish this invention, but he did utilize India rubber to form the veins and arteries of the automaton. Therefore, he is often credited with inventing the flexible rubber tube. This was Vaucanson's last work with automata. He apparently lost interest in his creations and sold them in 1743, possibly as a result of his entering government service.

In 1741, Vaucanson was appointed inspector general of silk manufacturing by Cardinal de Fleury (André-Hercule de Fleury), prime minister of Louis XV, who wanted to reorganize and improve France's silk-manufacturing industry, which was suffering severely because of competition from silk manufacturers in England and Scotland. Vaucanson visited silk factories in both France and Italy and quickly envisioned ways to make the industry profitable for France by improving the weaving process with new technology.

In 1745, Vaucanson introduced the world's first fully automated loom, refining the work of Basile Bouchon and Jean Falcon. In order to mechanize the weaving industry and automate the weaving process, Vaucanson developed a series of perforated cards (ancestors of today's punch cards) that guided hooks connected to the warp yarns. These techniques were not readily accepted by the workers, who resented the innovation, and many of Vaucanson's ideas were virtually ignored. At Lyon, workers even chased him and threw stones at him. However, his innovations in weaving were significant and long-lasting, as they were implemented later.

In 1746, Vaucanson was made a member of the Académie des Sciences. Denis Diderot and Jean le Rond d'Alembert called upon him to contribute to the mechanical and tool sections of their *Encyclopédie: Ou, Dictionnaire raisonné des sciences, des arts, et des métiers* (1751-1772). Vaucanson was responsible for the invention of a number of machine tools. This same year, he invented the first calender, a machine using rollers to smooth and create a special finish on the silk. In 1750, he invented a special machine to weave silk with a double twist. While mechanizing the tools of the silk-manufacturing industry, he also invented machines to make the tools. In 1751, he created the all-metal slide rest lathe and was the first to use a drill. For one of his machines, he created a special endless chain, which came to be known as the *chaîne Vaucanson* (Vaucanson chain). In 1757, Vaucanson introduced an improved calender.

In addition to improving the methods used in weaving and developing new machines, Vaucanson reorganized the industry by setting up new weaving shops and building establishments to make the looms and other machinery necessary to silk manufacturing. In 1764, he set up a shop at Montpellier, and in 1768 a lathe manufacture at Amboise. From 1773 to 1778, he was involved in establishing additional manufacturing units. In 1778, he fell and his health deteriorated rapidly, resulting in his death in Paris on November 21, 1782.

IMPACT

Toward the end of his life, Vaucanson collected together his own works and those of others that he found significant and left them to King Louis XVI, who was also fascinated by mechanical technology. This collection provided the foundation pieces for the Conservatoire National des Arts et Métiers in Paris.

Although Vaucanson's efforts in 1745 to automate the French silk-weaving trade met with intense resistance from the weavers, and though many of his inventions were not put into general use, his work was eventually of great importance to the weaving industry. Using his system of punch cards, Joseph Marie Jacquard, a weaver and inventor, perfected the Jacquard loom from 1804 to 1805. This loom made possible the rapid weaving of intricate patterns and virtually revolutionized the weaving business. The lathe, drill, and other tools that Vaucanson invented made possible the automation of manufacturing and rapid production of standardized products.

With his automata, Vaucanson made a significant contribution to the development of the field of human physiology and to the creation of mechanical devices to replicate the body's functions, thus enabling advances in medicine. The automata also laid the basis for the field of robotics. In addition, the punch-card technology created by Vaucanson provided the groundwork for the development of computer technology in the twentieth century. Punch cards were used to input data and to store information in binary form.

—*Shawncey Webb*

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See also: Charles Babbage; Ctesibius of Alexandria; James Hargreaves; Hero of Alexandria; Herman Hollerith; Al-Jazarī; John Kay.

ALESSANDRO VOLTA

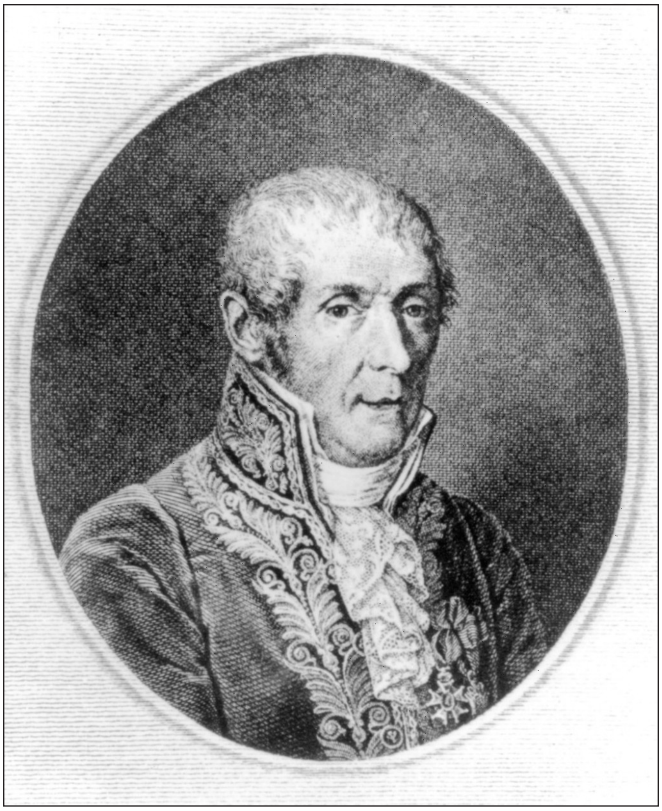
Italian physicist

Most famous as the inventor of the electric battery, Volta also invented other electrical devices, including the electrophorus and microelectroscope, as well as an eudiometer for measuring air's purity.

Born: February 18, 1745; Como, Duchy of Milan (now in Italy)
Died: March 5, 1827; Como, Kingdom of Lombardy-Venetia (now in Italy)
Also known as: Alessandro Giuseppe Antonio Anastasio Volta (full name); Count Volta
Primary fields: Chemistry; physics
Primary inventions: Voltaic pile (electric battery); electrophorus

EARLY LIFE

Born into a struggling noble family in 1745, Alessandro Volta (ah-lay-SAHN-droh VOHL-tuh) had, in his early years, to adapt himself to his father's straitened circumstances and to being the youngest of seven (of nine) children who survived to adolescence. His father, Filippo, had been a Jesuit for eleven years, a training that did not equip him to be a good provider. His mother, Maddalena dei Conti Inzaghi, was twenty-two years younger than her husband. Since Alessandro did not speak until he was four, his father and mother assumed that he was mentally impaired, but within a few years he exhibited signs of being more quick-witted than his brothers and sisters. After his father died, Alessandro, who was still a child, went with his mother and two sisters to live with an uncle, an archdeacon in the Como cathedral. Roman Catholicism would have a profound influence on the Volta family (two of his sisters became nuns; three of his brothers, priests). Throughout his life, Volta grappled with reconciling his Catholicism and the secular Enlightenment philosophy that undergirded the new science to which he was strongly attracted.



Alessandro Volta. (AIP Niels Bohr Library)

Records concerning Alessandro's early education no longer exist, but from later correspondence it is known that, as a teenager, he attended, as a boarder, the Jesuit college at Como, where he received a disciplined training in languages, including Latin and French, Italian literature, and philosophy. However, an uncle, a member of the Dominican order, feared that Alessandro would be recruited by the Jesuits, and he withdrew him, sending him to one of the town's seminaries. Although the diocesan priests were not as learned as the Jesuits, Volta was able, through friendships, to develop his growing interest in natural philosophy, particularly electricity. He even wrote a long Latin poem in which he praised the chemical and electrical discoveries of such natural philosophers as Joseph Priestley. Despite family pressure to pursue advanced learning in law or some other practical profession, Volta decided to follow his heart. Even before leaving school in 1765, he had begun corresponding with an eminent French physicist, Jean-Antoine (Abbé) Nollet, to whom he explained his idea that electrical phenomena could be understood through analogies with magnetic and gravitational forces. He also corresponded with Giovanni Battista Beccaria, a physics professor at the University of Turin, and it is to this physicist that Volta addressed his first publication in electrical studies.

Life's Work

By 1769, the time of his first scientific publication, Volta had completed his formal education and become a teacher of physics at the Royal School in Como. His seventy-two-page treatise, *De vi attractiva ignis electrici* (on the attractive force of the electric fire), was derived from electrical experiments of Benjamin Franklin and Beccaria, and from physical ideas of Sir Isaac Newton and Roger Boscovich. Although most contemporary physicists accepted a dualistic theory, Volta shared with Franklin a belief in a single electric fluid, and he thought that two objects possessing unequal amounts of this electric "fire" would attract each other with a force proportional to their imbalance.

After the Jesuit order was suppressed in 1773, its college in Como became state property, and in 1774 Volta was hired as its superintendent and director, with the task of modernizing its curriculum. He had sufficient time to continue his electrical studies, and he announced, in 1775, his first invention, an electrophorus. This device—consisting of a metal plate covered with resin, wax, or ebonite, and a second metal plate with an insulated handle—was able to produce static electricity by means of electrostatic induction. Volta's charge-accumulating machine was called "the most intriguing electrical device since the Leiden jar." This invention made Volta famous, and he even suggested that it might be used in an electrical message system from Como to Milan.

Volta's enhanced reputation led, in 1778, to an offer of a professorial appointment at the University of Pavia. He accepted this position, which allowed him to continue his work as an experimental physicist. He constructed one of the best laboratories in Europe, which enabled him over the next four decades to make important discoveries in electricity, chemistry, and meteorology. A few years before this move, Volta had become interested in the study of gases, then called chemical pneumatics. He had collected a gas from lakeshores and marshes, then investigated its properties, most notably its extreme flammability. His discovery of "marsh gas" (today's methane) led to marsh-gas lanterns and his invention of the "electric pistol," in which a spark exploded this gas.

The Voltaic Pile

Because of the absence of many primary documents, scholars have found it difficult to determine precisely how Alessandro Volta discovered the first electric battery. Nevertheless, the story that has been pieced together from a variety of sources is a fascinating one in which the frog and electric fish played influential roles. Evidence certainly exists that Volta was intrigued by Luigi Galvani's discovery of "animal electricity" through his experiments with frog's legs, although, in 1794, Volta formulated an explanation that dissimilar metals were primarily responsible for the phenomenon. In his contact (or metallic) theory, Volta was even able to show that the "electromotive force" developed depended on how far apart the metals were in the following series: zinc, tin, lead, iron, copper, platinum, gold, and silver. Consequently, the most effective pair in producing electricity was zinc and silver.

According to some scholars, the event that precipitated Volta's discovery of the battery was his reading of a 1799 paper by William Nicholson on the detection of weak electricity, in which he discussed a model for an electrical device based on the anatomy of the electric (or torpedo) fish. Nicholson's idealized model had different disks in opposing electrical states. Although Volta disagreed with this model, it stimulated him to pile zinc and silver disks with other disks of felt or cardboard that had been saturated with brine. Through experimentation, he discovered the following series for his column of disks: silver, zinc, cardboard, silver, zinc, cardboard, and so on. When Volta touched the highest and lowest disks simultaneously, he received an electric shock, and when he connected these with a wire, he got a continuous flow of electricity.

Other scholars think that Volta first discovered the battery by experimenting with a series of goblets filled with salt or acid solutions. These goblets were bridged by different metals that had been soldered together. Volta illustrated the second part of his paper announcing the battery with diagrams of both the pile and the series of goblets (called the "crown of cups"). He sent this two-part paper to Joseph Banks, president of the British Royal Society, who published it in the society's *Transactions* in 1800. Volta suggested two possible names for his device: "artificial electric organ" (in analogy with the natural electric organ of the torpedo fish) or "electromotive apparatus" (for its capacity to set the electric fluid in motion). Others called it "Volta's pile" or the "voltaic pile," but its resemblance to the batteries (or yoked units) of Leiden jars, used since the 1740's, led to the name "battery." Unlike these earlier batteries, which needed to be charged after each discharge, Volta's pile provided a continuous source of electric current. In 1881, Volta's own name became an important electrical unit, the volt, a measure of the force that drives an electric current.

European trips in the late 1770's and early 1780's consolidated Volta's reputation as an accomplished experimenter. For example, in 1781 he met in Paris the naturalist Georges-Louis Leclerc, the astronomer Pierre-Simon Laplace, and the chemist Antoine Lavoisier. In 1782, he spoke with his boyhood hero Joseph Priestley in England. On his return to Pavia, he continued his experiments in electricity and chemistry. He improved the eudiometer, the instrument chemists used to determine the amount of "dephlogisticated air" (today's oxygen) in common air, and he found that air is about one-fifth oxygen.

An electroscope is an instrument for measuring the quantity of electric charge, but with Volta's invention of the microelectroscope, scientists, especially meteorologists interested in atmospheric electricity, had a way to detect and quantify extremely weak electricity. In this way, Volta helped to found the new field of electrometry, and his discovery of exactly how air expands with increasing heat helped to establish a basic law useful to both physicists and chemists.

In the 1790's, Volta became involved in a controversy with Luigi Galvani over the interpretation of Galvani's discovery that dissected frog legs twitched in the presence of an electrostatic machine. Galvani saw this as evidence for "animal electricity," whereas Volta explained the phenomenon mechanistically, as solely due to the contact of different metals with wet substances in the dead frog. The debate spread beyond Italy, and Galvani's position was supported by such distinguished natural philosophers as Alexander von Humboldt and Volta's position by Charles-Augustin Coulomb, who had discovered the quantitative law of attraction between electrostatic charges.

In the midst of this controversy, and while important changes were occurring in his personal life, Volta created his most famous invention. He had fallen in love with an opera singer, but family opposition prevented this union. In 1794, he married Teresa Peregrini, the youngest of seven daughters of a count, and their three sons were born in 1795, 1796, and 1798. Toward the end of 1799, Volta constructed his first device that produced a constant flow of electricity. In one version, he stacked copper and zinc disks, interspersed with brine-soaked felt, into a "voltaic pile," which constituted a battery. This invention was Volta's crowning achievement, and after it was published in 1800 he was showered with honors. For example, Napoleon I invited him to Paris, where he received a gold medal, the Cross of the Legion of Honor, and six thousand francs. He was later made a count and a senator of the Kingdom of Lombardy.

In the remaining decades of his life, Volta invented little of significance and cut back on his teaching and administrative duties. In 1816, his collected works were published in five volumes in Florence, and in 1819 he retired to his family's country estate in Como. Here he was visited by such scientists as Humboldt and such dignitaries as Prince Christian of Denmark. After a long illness, Volta died in 1827 and was buried in the family plot not far from Como.

IMPACT

Volta, "the Newton of electricity," had great influence even during his lifetime, especially through his invention of the electric battery. For example, soon after the battery became public, the chemist William Nicholson built England's first voltaic pile, and, with the help of a friend, he used it to "electrolyze" water, thus breaking it into its component elements, hydrogen and oxygen. Several years later, another English chemist, Humphry Davy, used a powerful voltaic pile to electrolyze a series of molten salts, thereby discovering such new elements as potassium, sodium, barium, strontium, calcium, and magnesium. Davy's interpretation of the battery as a device that converted chemical changes into electricity actually prevailed over Volta's contact theory. The voltaic pile became an essential instrument not only for chemists but also for such physicists as Hans Christian Ørsted and Michael Faraday, who employed it in making such significant discoveries as electromagnetism and electromagnetic induction.

During his lifetime, Volta was seen as an ingenious inventor of electrical instruments, someone who had "his brain in his fingertips," rather than as an astute theoretician. His contact theory proved wrong, and his adherence to the outdated phlogiston theory (which held that combustible substances contained a weightless fluid called phlogiston) in chemistry was misguided. His lack of expertise in advanced mathematics meant that he was unable to transform his ideas of electrical attraction, tension, and capacity into full-fledged theories. Nevertheless, his instruments did foster the discoveries that helped to create the great theories of electricity and magnetism developed in the nineteenth century. After Volta's death, his battery had a growing number of practical applications, such as the development of electric telegraphy in the 1840's. From the perspective of the twenty-first century, scholars now describe Volta's invention of the battery as "epochal," comparable in significance to the telescope in advancing science. Others have compared its importance to the steam engine, since it played an important role in transforming society. Electrical current became an integral part of advanced industrial societies, and current electricity had its origin in Volta's felicitous invention.

—*Robert J. Paradowski*

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See also: Sir Humphry Davy; Michael Faraday; Benjamin Franklin; Sir Isaac Newton; Joseph Priestley; Lewis Urry; Charles Wheatstone.

FAUST VRANČIĆ

Croatian mathematician, physicist, and philosopher

Vrančić was regarded as something of a Renaissance man for the range and diversity of his interests and achievements. Most notable was his illustrated book of inventions, Machinae novae, *which included the first printed design of a parachute.*

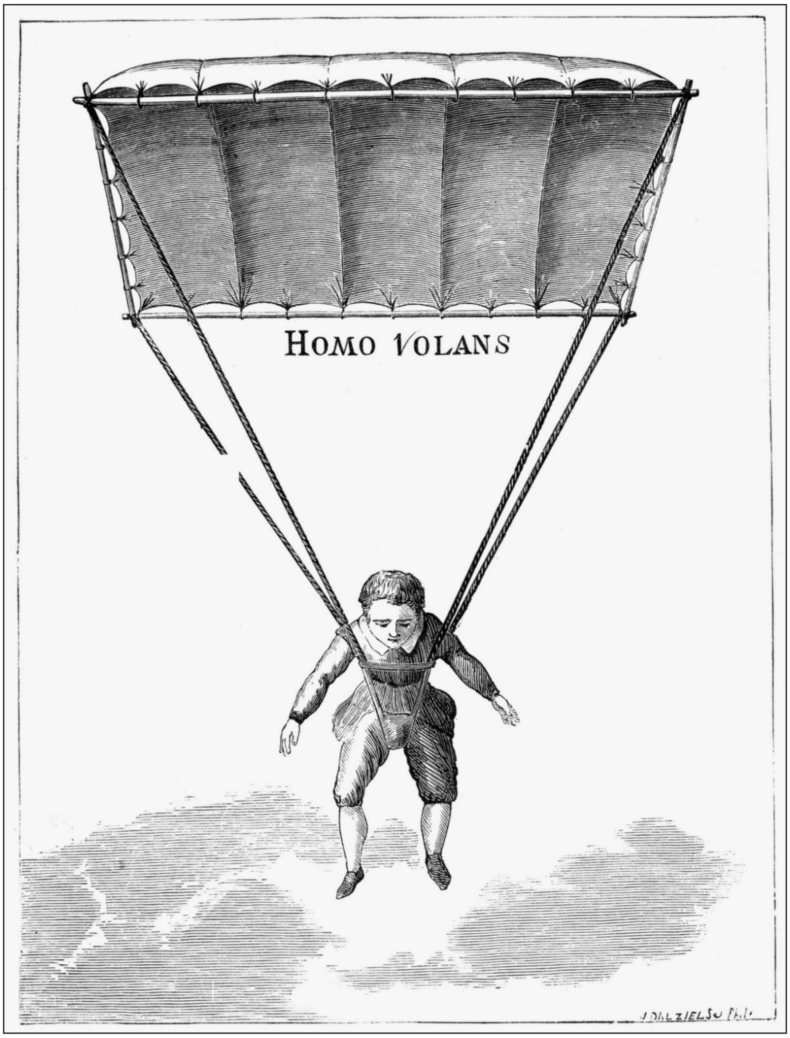
Born: 1551; Šibenik, Dalmatia (now in Croatia)
Died: January 17, 1617; Venice (now in Italy)
Also known as: Fausto Veranzio; Faustus Verantius
Primary field: Physics
Primary invention: Parachute design

EARLY LIFE

Faust Vrančić (fowst VRAWN-chihk) was born into an aristocratic family near the Dalmatian town of Šibenik, just across the Adriatic Sea from Italy. His early education was in the household of his uncle, who was successively archbishop and cardinal primate of Hungary. Vrančić completed his education in Italy, which retained its Renaissance reputation for first-rate schools. There he studied philosophy, law, and mathematics. He had no known training in engineering.

In 1581, the Emperor Rudolf II named Vrančić counselor and secretary of the imperial chancery for Hungary, a key administrative position in an important region of the empire. The influence of Vrančić's uncle was likely a factor in this selection. For the next thirteen years, Vrančić served the emperor as administrator and diplomat. He often resided at the imperial court in Prague, Bohemia, where the emperor, a dedicated patron of science as well as the arts, had assembled many of the most distinguished scientists and engineers of the day. Vrančić flourished in this lively intellectual environment.

However, the death of his wife prompted Vrančić's resignation from the emperor's service in 1594. Vrančić became a priest and then a titular bishop before entering a monastery in Rome where he resumed several long-delayed scholarly projects. He completed two histories and published treatises on logic, theology, and Christian ethics. Vrančić had earlier published a dictionary of five European languages that contained many entries of scientific and engineering terms not found in other dictionaries. Overall, the scope and quality of his literary



The "Homo Volans" (flying man) parachute invented by Faust Vrančić. (The Granger Collection, New York)

achievements were impressive, but it was in the realm of science and technology that Vrančić would leave his mark.

LIFE'S WORK

Vrančić's interest in machines had been intense since his student days in Italy, where the exciting potential of technology was well understood. Evidence of this was all around, as in the elaborate sprinkler systems installed by many wealthier Italians to maintain their private gardens.

In 1595, Vrančić published a book that had been in preparation for many years. He titled it *Machinae novae* (new machines). This folio volume contained forty-nine copperplate engravings of various machines, accompanied by concise explanations in Latin and Italian. He described eleven other devices, not pictured, which raised the total number to sixty. Vrančić had seen many of the machines over the years, but most were of his own invention or were revised versions of existing machines. A new edition of the book in 1615 translated the text into three other languages.

The devices described in *Machinae novae* ranged across a broad spectrum. Prime among them were mills, dredging machines, aerial trams, bridges, and, above all, the design of a parachute. Mills were clearly of special interest to Vrančić. He displayed some eighteen varieties, all of which were powered by readily available natural resources of water or wind. For example, he conceived of a mill situated along coastal waters capable of trapping tidewaters in "accumulation pools" during high tide. At ebb tide, gravity would guide the flow of receding water to drive a millstone for grinding grain. Vrančić also designed windmills that, similar to modern airplane wings, had flaps on their blades for catching more wind.

Another of Vrančić's innovations was a water-powered dredging machine mounted on a barge. Its purpose was to clear rivers and other waterways of sediment that could hinder boat traffic. Vrančić's dredger had a paddle wheel with a horizontal shaft to which wooden arms were attached. The current of the river would rotate the shaft and its arms to scrape the riverbed.

Elsewhere, Vrančić cleverly addressed the problem of how to move people and freight up a steep incline. He contrived a kind of aerial tramway that could, in theory, transport cargo by suspending carriages from rope cables strung along a series of towers. As one cargo carrier was manually raised up the incline, the second would automatically descend. Each carrier served to counterbalance the other and give it impetus.

Vrančić also made a major contribution to bridge technology. He had studied dozens of bridges in his trips around Europe as a diplomat. In *Machinae novae*, he described two basic kinds of bridges that he modified considerably from the conventional arch and beam bridges he had observed. The suspension bridge had originated in ancient China but remained unknown in Europe until Vrančić published a drawing of it in his book. It is not known where he found the idea. His sketch of the "cable-stayed," or cable-supported, bridge was the first printed version.

Both types of bridge, suspension and cable-stayed, required pillars or towers built at each end of the floor or deck over the chasm to be spanned. The two types differed in how the cables were attached. Suspension bridge cables were composed of heavy rope connected over each tower to anchors at the end of the bridge deck. This transmitted the full weight of the deck to the tower. In Vrančić's cable-stayed bridges, cables made of rope connected at regular points to the nearest tower before descending to connect at regular points along the edge of the deck. This placed the main pressure on the deck. Vrančić also designed a hybrid bridge with features of both the suspension and the cable-stayed types. He replaced the rope cables with iron chains linked to each other by eyebars made of brass. These various bridge models were not actually built until the nineteenth and twentieth centuries, but they remain popular today.

Of all Vrančić's devices, one in particular captured the popular imagination, namely his design for a parachute. Toward the end of his book, wedged between depictions of dredging machines and different kinds of boats, was a striking illustration of a man dangling from a square parachute, having just jumped from a church bell tower. While this drawing resembled a sketch by Leonardo da Vinci done more than a century before, Vrančić's version was simpler and more practical in design. It was also the first printed illustration of a parachute. The conceptions of Leonardo and Vrančić were themselves part of a history of experiments with parachute-like devices that reflect the recurrent human fascination with flight.

The Parachute

The ancient Chinese had the idea of a parachute as a kind of umbrella, but it did not always take that shape outside China. For example, the venturesome ninth century Arab ʿAbbas ibn Firnas jumped from a high place wearing a billowing cape complete with wooden struts to keep his cape more open to the air. However crude the device, the clear intent was to break the force of the fall through the friction of air against an unfurled cape.

In Renaissance Italy, the parachute idea was among many others that received fresh attention. An unpublished manuscript dated about 1470 contained a sketch by an unknown artist of a cone-shaped parachute made from cloth. The jumper was equipped with two long cloth streamers attached to two wooden bars that he held in his hands. The bars were fastened to his belt by cords. He had a sponge in his mouth to protect against the shock of landing. The streamers were clearly intended to break his fall, but this does not seem much of an improvement over the billowing cape of the medieval Arab. Nonetheless, this unknown Italian engineer managed around 1470 to conceive of what might be the first true parachute device in history.

A few years later, just after 1480, the great Italian engineer, inventor, and artist Leonardo da Vinci sketched in the margin of his notebook his own conception of a parachute. It is doubtful whether he had seen the version by the anonymous engineer, but similar ideas were circulating at the time. In any case, Leonardo had closely observed the wing motion of birds in flight, especially the resistance of air under the wings. Leonardo's parachute differed significantly from that of his predecessor. First, it was shaped like a pyramid rather than a cone. He conceived of the canopy as the central element of a rigid-framed, four-cornered structure attached by metal rods to each corner of the canopy. Cords of rope connected to the rods converged in the outstretched hands of the jumper, who is shown hanging on with obvious determination since he would be in immediate free fall should he let go. Leonardo's device was a clear improvement over the parachute with the streamers.

Finally, just over a century later, Faust Vrančić depicted in his *Machinae novae* (1595; new machines) a parachute launched from a tower. Its canopy, like Leonardo's, was square-shaped and rigid-framed, and it also featured long rope cords secured by rods to each corner of the parachute. Unlike Leonardo's device, the cords descended to a harness at the man's waist. Finally, secured by the rope cords, the chutist's body hung loosely and his arms extended out from his body, almost like wings. Vrančić titled the sketch "Homo Volans" (flying man). No firm evidence supports the rumor that Vrančić built and personally tested his device.

The first parachute known to have performed successfully was constructed and manned in 1783 by a Frenchman, Louis-Sébastien Lenormand. The device became widely popular with the advent of the airplane in the early twentieth century. As the first to put the concept and the model of a parachute into print, Vrančić has merited a prominent place in the history of this valuable, multipurpose apparatus.

IMPACT

Vrančić was a true man of the Renaissance. In addition to a distinguished public career as royal administrator, diplomat, and churchman, he displayed impressive scholarly expertise as philosopher, historian, lexicographer, and Christian humanist. Despite these achievements, he would be known above all for his history of technology, *Machinae novae*. In this work, Vrančić depicted and described a wide variety of technical designs, many for the first time. He offered practical solutions to common problems by presenting labor-saving machines to improve everyday living. Still, for Vrančić and many of his fellow engineers, there was also, beyond any solely utilitarian motivation, the pure joy of discovery. He most likely never built or tested any of the models he sketched. In any event, Vrančić demonstrated how water and air could be readily adapted to worthy agricultural, commercial, or personal uses. Among his water-dependent devices were dredging machines, suction pumps, and watermills of several kinds. Windmills and the parachute relied necessarily on the air.

As to Vrančić's originality, he did invent devices like a water suction pump, a wooden vertical waterwheel, and a flywheel similar to that used in modern engines. He also drew the first printed sketch of a parachute and of a cable-stayed bridge. His drawing of a suspension bridge reinforced by chain links of iron connected by eyebars was probably original as well.

Nevertheless, Vrančić was less a major inventor than a significant transmitter of technological ideas to future generations. Many of the concepts and mechanisms in *Machinae novae* would come to fruition in the great age of machine technology in the eighteenth and nineteenth centuries, which culminated in the Industrial Revolution. This movement would in turn transform civilization.

—*Donald D. Sullivan*

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See also: ʿAbbas ibn Firnas; George Cayley; Louis-Sébastien Lenormand; Leonardo da Vinci; Joseph-Michel and Jacques-Étienne Montgolfier.

SELMAN ABRAHAM WAKSMAN

Russian American biochemist and microbiologist

Waksman's research into soil microorganisms and their processes and interactions led to the discovery of streptomycin, actinomycin, and numerous other antibiotics. His work was critical to enhancing public health worldwide.

Born: July 22, 1888; Priluka, Russia (now in Ukraine)
Died: August 16, 1973; Hyannis, Massachusetts
Primary fields: Agriculture; biology; medicine and medical technology
Primary invention: Antibiotics

EARLY LIFE

Selman Abraham Waksman (WAHKS-mehn) was born the son of Jewish parents, Jacob Waksman and Fradia London Waksman, in the rural Ukrainian town of Priluka in what was then Russia. He received his early education primarily from private tutors and completed his school training in Odessa in an evening school. He studied the Torah and Talmud for many years as well. As a result of childhood experiences with anti-Semitism and with the unsuccessful revolution of 1905, Waksman concluded that he could not achieve his personal and professional goals in czarist Russia.

In 1910, after obtaining his matriculation diploma from the Fifth Gymnasium in Odessa as an extern, Waksman emigrated to the United States, settling with his cousin, a chicken farmer, in Metuchen, New Jersey. He worked there for a few years on a family farm and by fall, 1911, enrolled in Rutgers College (now Rutgers University) in New Brunswick, having won a state scholarship. He received his bachelor of science degree in agriculture in 1915, graduating Phi Beta Kappa.

By 1916, Waksman had become a naturalized U.S. citizen. He was appointed research assistant in soil bacteriology under Dr. Jacob Lipman at the New Jersey Agricultural Experiment Station and was permitted to continue graduate work at Rutgers, earning his master of science degree in 1916. In the same year, he was appointed a research fellow at the University of California, Berkeley. Waksman received his Ph.D. in biochemistry after only two years.

Waksman's decision to enter an agricultural rather than a medical career was inspired by Dr. Lipman, a bacteriologist, the dean of the College of Agriculture, and also an immigrant from Russia. Courses in bacteriology with Lipman and summer projects with Dr. Byron Halstead, a plant nutritionist and geneticist, strongly influenced Waksman's future career. After receiving his doctorate from the University of California, Berkeley, in 1918, Waksman secured a position at the Rutgers Bacteriology Department, where he continued his research on soil actinomycetes and fungi.

LIFE'S WORK

Upon Waksman's return to Rutgers, his initial task was to complete earlier investigations in the nature and abundance of the actinomycetes in soil, including the delineation of their physiological and biochemical processes. Much of his energy was consumed during the next two years by a position with a local industrial laboratory and in developing a course in soil microbiology; however, all time available for research was devoted to the actinomycetes.

Selman Abraham Waksman. (©The Nobel Foundation)

Following studies of microbial interactions in the decomposition of plant residues, Waksman conducted a comprehensive investigation of the ecological relationships of soil microorganisms. He also described new thiobacilli involved in the oxidation of elemental sulfur. His results demonstrated that actinomycetes exert a substantial influence on the activities of soil bacteria and fungi.

During the 1920's and 1930's, Waksman traveled throughout the United States, Europe, and the Middle East, conducting systematic studies of the biology of peat soils and compost piles. He met several noteworthy soil microbiologists, including Sergei Winogradsky. Waksman developed professional relationships with industries that produced enzymes and other microbially generated products, thus establishing the vanguard of entrepreneurs in the modern biotechnology industry.

During the 1930's, Waksman and his colleagues engaged in methodical efforts to identify soil organisms producing substances with potential for control of infectious diseases. Two events provided the stimulus for this focus. One was the work of a former student, R. Dubois, on the identification of two polypeptides (gramicidin, tyrocidine) by soil bacilli that have a lethal effect on disease-causing bacteria. Waksman believed that fungi and actinomycetes would provide far more effective antibacterial agents than the bacteria. The looming threat of World War II provided the second stimulus, which underscored the need for new agents for the control of infections and epidemics that would presumably arise.

The first antibacterial substance Waksman identified was from *Actinomyces antibioticus*, a member of the actinomycetes family. The microbe produced a substance that he termed actinomycin, which possessed both bacteriostatic and bactericidal properties. This discovery was soon followed by the isolation of other antibacterials. An antibiotic labeled streptothricin was identified within a culture of an actinomyces. This substance was soluble in water, stable to heat, and active against both gram-positive and gram-negative bacteria. Streptothricin was considered a new type of antibiotic that could supplement penicillin. It soon became apparent, however, that this substance was not an ideal chemotherapeutic agent since it exerted undesirable effects in mammalian systems. The discovery of streptothricin was, however, a major step forward in Waksman's investigations of antibiotics.

Antibiotics

Antibiotics are derived wholly or partially from selected microorganisms. The term "antibiotic" (from the Greek for "fit for life") was coined by Professor Selman Abraham Waksman in 1942 to describe any substances produced by microorganisms that were antagonistic to the growth of other microbes. Many antibiotics are relatively small molecules having a molecular weight less than 2,000 daltons. Antibiotics can be categorized based on their target specificity: Narrow-spectrum antibiotics are used against specific bacterial types, such as gram-negative or gram-positive bacteria, while broad-spectrum antibiotics can be used effectively against a wide range of bacteria.

Prior to Waksman's discoveries, treatments for infections often consisted of administering broad-spectrum (and potentially host-toxic) compounds such as strychnine. In contrast, antibiotics derived from microbes impart few side effects and enjoy precise and effective activity at its target. Most antibacterial antibiotics have no activity against viruses, fungi, or other microbes. Antibiotics are among the most frequently prescribed medications in modern medicine. Some antibacterials are known to kill bacteria (that is, they impart bactericidal effects), whereas others prevent bacteria from multiplying (bacteriostatic effects).

The first antibiotic was penicillin, discovered accidentally in 1928 by Alexander Fleming while he was experimenting with a culture of *Staphylococcus*. Today, more than one hundred different antibiotics are available to treat both minor ailments and life-threatening infections. The majority of antibacterials originate from a small group of compounds. The main classes of antibiotics include penicillins, cephalosporins, macrolides, fluoroquinolones, sulfonamides, tetracyclines, and aminoglycosides.

With advances in medicinal chemistry, most antibiotics are now modified chemically from compounds discovered within natural environments. Some antibiotics are still produced and isolated from living organisms; many others have been formulated through purely synthetic processes. In recent years, three new classes of antibiotics have been brought into clinical use. These new antibiotics show promise as a means to counteract the growing bacterial resistance to conventional antibiotics.

Waksman formulated simple microbial screening techniques and applied these to soil and other natural materials. By 1940, Waksman and his colleague H. B. Woodruff had devised a technique for identifying natural substances with antibacterial properties. The screening was conducted by looking for growth inhibition zones around single colonies of isolated soil microbes grown under a variety of culture conditions, then testing the inhibition on specific pathogenic bacteria.

In September, 1943, Waksman succeeded in isolating an organism that produced an antibiotic that possessed properties similar to those of streptothricin but that was less toxic to the host. The new antibiotic was named streptomycin after *Streptomyces*, the group of actinomycetes that produced sporulating aerial mycelia. Waksman and his colleagues screened more than ten thousand different soil microbes before streptomycin was isolated. Streptomycin was capable of destroying the tubercle bacillus and was considered safe enough to test in humans. Subsequent clinical trials proved that streptomycin cured several types of tuberculosis and that it was safe enough to prescribe for a variety of gram-negative bacterial infections.

Within a decade, ten antibiotics were isolated and characterized in Professor Waksman's laboratories, three of them with important clinical applications: actinomycin (1940), streptomycin (1943), and neomycin (1948). He proposed the now standard term "antibiotics" for this class of natural growth inhibitors. Eighteen antibiotics were eventually discovered under Waksman's direction. With each new phase in the development of the antibiotics program in Waksman's laboratory, progress was made in understanding the type of antibiotic that was necessary to treat a specific pathogen, and in methods for its production and isolation.

In response to his concerns about fascism in Europe, Waksman created an association with the Oceanographic Institute in Woods Hole, Massachusetts. He established a laboratory there for the study of marine microbiology. One study there, for the U.S. Navy and Coast Guard, was concerned with fouling of oceangoing vessel bottoms. Waksman was appointed marine bacteriologist at the institute, where he served until 1942. He was then elected as a trustee, and later a life trustee. He and several students worked at Woods Hole each summer over the next decade or more.

Industry and research organizations began to study actinomycetes for their ability to produce antibiotics and vitamins. To meet the growing interest, Professor Waksman published in 1953 a volume entitled *Guide to the Classification and Identification of the Actinomycetes and Their Antibiotics*. With his discovery of streptomycin in 1943, Waksman initiated a professional relationship with Merck and Company, which developed liquid culture methods for bulk production of microbial products.

Waksman patented and licensed his antibiotics, and he donated 80 percent of his patent earnings to Rutgers University. In 1951, Rutgers University established an Institute of Microbiology and made Waksman its first director. The institute was endowed and supported by the assignment of Waksman's streptomycin patent royalties to Rutgers. Waksman established the Foundation for Microbiology in 1951 and assigned one-half of his personal royalties for its support.

IMPACT

In Waksman's day, microorganisms were considered significant to medicine primarily as causes of disease. Microbes were also noteworthy in terms of public health in connection with water contamination and purification, and in food processing and agriculture. Soil microorganisms were recognized as critical for the decomposition of plant and animal remains, returning elements such as carbon, nitrogen, oxygen, and others to the air and soil via a range of biogeochemical cycles. Microbes, however, had yet to be shown to be of value in the industrial production of vitamins, enzymes, and antibiotics.

Waksman's work transformed the actinomycetes from interesting laboratory creatures to organisms of highly practical significance, which yield chemical substances used for combating numerous infections of humans, animals, and plants. Professor Waksman, together with his students and associates, isolated a range of new antibiotics including actinomycin (1940), streptothricin (1942), streptomycin (1943), grisein (1946), neomycin (1948), clavacin, fradicin, candicidin, candidin, and others. Two of these, streptomycin and neomycin, have found extensive application in the treatment of numerous infectious diseases of humans, animals, and plants. The patent on streptomycin has been designated as one of the ten "patents that shaped the world."

During his lifetime, Waksman received numerous awards and honorary degrees for his scientific work. He was elected to the National Academy of Sciences in 1942. He was awarded the Nobel Prize in Physiology or Medicine in 1952 "for his discovery of streptomycin, the first antibiotic effective against tuberculosis." This distinction earned him the title of the "father of antibiotics."

Waksman has emphasized that fundamental scientific investigations will sooner or later lead to practical applications: "It is essential to gain fundamental knowledge; the application will come sooner or later."

—*John Pichtel*

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See also: Carl Djerassi; Gertrude Belle Elion; Robert Charles Gallo; Ida H. Hyde; Edward Jenner; René-Théophile-Hyacinthe Laënnec; Naomi L. Nakao; Jonas Salk; John C. Sheehan.

MADAM C. J. WALKER

American entrepreneur and hair stylist

Walker created hair care products that have been used by thousands of women both in the United States and abroad. More significantly, she developed business and marketing strategies that allowed women, particularly African American women, to become financially independent.

Born: December 23, 1867; Delta, Louisiana
Died: May 25, 1919; Irvington-on-Hudson, New York
Also known as: Sarah Breedlove McWilliams Walker (full name); Sarah Breedlove (birth name); Madam Charles Joseph Walker
Primary field: Business management
Primary invention: Hair care products

EARLY LIFE

Madam C. J. Walker was born Sarah Breedlove to Owen and Minerva Anderson Breedlove; she was the fifth of six children. She was the couple's first child born outside slavery. Sarah became an orphan at the age of seven. She and her sister survived by working in cotton fields in both Louisiana and Mississippi. Sarah had very little formal education, but she improved her reading and writing skills through tutoring by women at the African Methodist Episcopal church she attended in St. Louis. At the age of fourteen, she married Moses McWilliams, largely to escape abuse from her sister's husband. When McWil-

Madam C. J. Walker, the first female self-made millionaire in the United States. (Michael Ochs Archives/Getty Images) liams died two years later, she moved to St. Louis with her only child, Lelia (born June 6, 1885), to join her four brothers, who were establishing themselves as barbers. Making only $1.50 per day, she managed to educate her young daughter. She also took jobs as a washerwoman and a cook to help support herself and Lelia.

LIFE'S WORK

During the 1890's, Sarah began to suffer from a scalp ailment that caused her to lose most of her hair. She began to experiment with both homemade remedies and store-bought products. In 1905, she moved to Denver, Colorado, where she married Charles Joseph Walker, and she became known as Madam C. J. Walker. Eventually, she created Madam Walker's Wonderful Hair Grower from a recipe she claimed had been revealed to her by a man in a dream. Her husband felt that she should be satisfied with making ten dollars per day; she disagreed, and the two were divorced. Madam Walker began to build her company: She was solely responsible for the sales, marketing, development, and distribution of her hair and skin care products—a feat unheard of at the time for any woman, let alone an African American woman.

While Walker's hair grower was a great invention, it was not the first of its kind. Walker worked for a short period for Annie Malone, an African American entrepreneur who had a hair care product before Walker invented her own. Walker's product line eventually expanded beyond her hair grower: She invented other hair care products as well as skin creams. She ended up with a complete line of beauty products to fit the needs of black women throughout the world. Understanding that her beauty products need to be utilized appropriately, Walker made sure that her sales force trained women in the proper use of her products, creating the "Walker System." She emphasized customer service, wanting her clients to feel pampered and important. Walker's products included not only locally available ingredients but also ingredients imported from all over the world, including African countries. Unique to Walker's enterprise were the business and marketing strategies she implemented in the sale of her products. She started by selling her line door-to-door, demonstrating the proper use of her beauty products to black women in the southern and southeastern United States. This market had previously been ignored or misunderstood, and these women appreciated not only products designed for their needs but also the attention of a beautifully coifed black woman capable of showing them how to use the products. Walker's success grew.

INDEPENDENT BUSINESS OPERATION

Madam C. J. Walker is noted to have invented the concept of independent business operators, whom she called hair culturists. These women independently sold products in the community in which they lived. As a result, Walker's products reached a broad market while retaining the sense of being a local product. This early version of "thinking globally and acting locally" created a strong following for Walker's products: Those who purchased Walker's hair care line and beauty creams learned how to use them in their own homes.

Madam Walker trained her culturists well and emphasized their participation in the company by holding the Madam C. J. Walker Hair Culturist Union of America Convention, the first national meeting of businesswomen in the United States. The convention sought not only to motivate the saleswomen but also to encourage their political and social activism within their communities.

Another benefit of this type of product distribution is the development of brand loyalty. By owning the product formula, the factories that produced the products, the schools utilized to train sales associates in the use and sale of the products, and the salons in which individuals could have the products professionally applied could always be assured of receiving a genuine Madam C. J. Walker hair tonic or cream, not an impostor. They were welcome to tour the factory and watch "their" products being created. They knew that they were getting the "real thing," and they had the sense that it was created just for them. This type of brand management and brand loyalty became the foundational principle of the marketing of all sorts of products, from automobiles to breakfast cereals.

In 1908, Walker moved to Pittsburgh, Pennsylvania, where she opened Lelia College. There she trained individuals she named "hair culturists," who began to sell her products. In 1910, she moved to Indianapolis, Indiana, where she built a factory, hair and manicure salon, and another training school. By creating the sales force and venues through which her products would be sold, Walker increased brand loyalty.

Walker then organized her independent sales agents in local and state clubs, a practice still utilized today be companies such as Mary Kay, Tupperware, and Avon. The agents not only sold the products but also used the products themselves. As walking endorsements of the Walker line, these saleswomen built brand loyalty; as homemakers and single mothers—women who had much in common with the women to whom they sold Walker's line—they demonstrated the feasibility of earning one's own money and making a living. These sales agents were not simply employees of Walker's company; they were themselves entrepreneurs who could enjoy the fruits of business ownership. Hence, Walker's direct-marketing method became a popular small-business strategy, used to this day. The women Walker recruited and trained became part of a national sales force, who then went on to recruit and train other women to establish beauty shops in their homes, keep business records, and practice exceptional customer service.

A visionary when it came to protecting her brand, Walker owned the formulas for making her hair care products, the factories in which they were made, the training facilities to teach her hair culturists to use and sell the products, and the salons in which her products could be used. This created "two brands in one": Walker's hair care products could be used both at home, by the layperson, and by professionals who set the example of how the products should be used to give women an elegant look.

In a move employed by many of the largest companies in the world today, in 1917 Walker held a convention of the Madam C. J. Walker Hair Culturist Union of America in Philadelphia, considered the first national meeting of businesswomen in the United States. At this convention, Walker went beyond simply motivating her hair culturists to sell more of the Walker line of products. She also encouraged them to get engaged in political and social activism in the communities in which they lived. Walker led by example in this area, visiting the White House after a white mob had lynched three African Americans in Illinois. She donated one thousand dollars to the building fund of a "colored" YMCA in Indianapolis, and she contributed five thousand dollars to the antilynching movement of the National Association for the Advancement of Colored People (NAACP). In another brilliant marketing strategy, Walker popularized the use of famous spokespersons by having her product used and touted by Josephine Baker, one of the most popular African American entertainers in the world at that time.

Walker's company was in operation from 1905 to 1985, when the right to manufacture products using the Walker name was sold to another company. She died from complications of hypertension on May 25, 1919, in New York State at the relatively young age of fifty-one. She left a sizable estate and a business that continued to function and provide good jobs for more than six decades after her death.

IMPACT

Walker is often quoted as saying, "I got my start by giving myself a start." She took this concept further by not only giving herself a start but also giving a start to countless other African Americans through her innovative business practices and high-quality products that produced the results they promised. She brought beauty into the lives of women who where often working hard just to make ends meet. Some complained that she was trying to make African American women's hair look like that of white women. Walker retorted that she was simply trying to promote the proper care of hair for women.

While Walker invented a number of products and developed many business and marketing strategies, she is often credited with inventions that were not hers. She did not, for example, invent the straightening comb, although she did popularize its use. She did not create the first African American hair care product available for purchase; she in fact got her start working for an earlier inventor of hair care products for African Americans.

Walker is, however, noted as the first self-made female millionaire in the United States. At her death, her estate had an estimated value of between $600,000 and $700,000 (approximately $6 million to $7 million today). The value of her personal and business assets combined is believed to have exceeded $1 million. She also achieved such prominence that she counted such eminent social and political figures as W. E. B. Du Bois among her acquaintances.

The impact of Walker's work on the field of business is threefold. First, she changed the practice of direct marketing. Bypassing the "middleman," Walker brought the supplier directly to the customer and vice versa. This allowed feedback on the product line that led to quick corrections of product flaws as well as new products tailored to changing customer demands. Walker's second area of influence included the creation of a large galley of "business owners" and the concept of franchising products, as opposed to having a large cadre of employees. The result was not only financial independence and wealth for a large number of people but also the Walker company's freedom to focus on business products and services as opposed to employer-employee issues. Walker's third major contribution was the concept of woman-as-owner, a contribution that went beyond business to improve society as a whole. In a time when few women, and fewer African Americans, owned a business, Walker not only owned a company but also helped others to do so.

—*Doresa A. Jennings*

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See also: Garrett Augustus Morgan; Earl S. Tupper.

SIR ALAN WALSH

English physicist and chemist

Walsh invented atomic absorption spectroscopy to identify the presence of chemical elements in samples and determine their concentration. This method was quick, easy, accurate, highly sensitive, and free from interference. It revolutionized quantitative analysis and was widely applied to a variety of diverse areas.

Born: December 19, 1916; Hoddlesden, Lancashire, England
Died: August 3, 1998; Melbourne, Australia
Primary fields: Chemistry; physics
Primary invention: Atomic absorption spectroscopy

EARLY LIFE

Alan Walsh was born in England, approximately twenty miles north of Manchester, in Hoddlesden, a small borough of Darwen, Lancashire. His father, Thomas Haworth Walsh, managed a small family cotton mill in Hoddlesden. His mother, Betsy Alice Walsh (née Robinson), was a very warm and gracious woman. At ten years of age, Walsh attended the local grammar school in Darwen. He passed the Northern Universities Matriculation Examination in 1933. At sixteen, eyestrain persuaded Walsh to concentrate on mathematics, chemistry, and physics. He completed his Higher School Certificate Examination in 1935, and his physical science prowess won him an honors course in physics at the University of Manchester.

Walsh flourished at the University of Manchester. While there, he attended a lecture by Sir Lawrence Bragg, who had won the Nobel Prize in Physics in 1915 for his work on X-ray crystal structure analysis. Bragg's lecture captivated and energized the young Walsh and influenced him to pursue a research career. Walsh graduated from Manchester in 1938 and was awarded a research scholarship to pursue postgraduate research in physics. He initially worked on the structure of mineral crystals but later switched to crystal structures of beta-carotene, a chemical from plants that serves as a precursor to vitamin A. He only spent one year at the Manchester College of Technology, since the onset of World War II compelled Walsh to refocus his efforts. During the war, Walsh worked for the British Non-Ferrous Metals Research Association (BNF). Walsh continued to work on the beta-carotene project in his spare time after he moved to the BNF.

While at the BNF, Walsh analyzed metals from German war planes that had been shot down. He devised several methods for the rapid and accurate identification of aluminum, copper, and zinc alloys. In 1944, Walsh completed his work on beta-carotene and was awarded a master of science degree in 1944 for a thesis entitled "An X-ray Examination of Beta-carotene."

THE ATOMIC ABSORPTION SPECTROPHOTOMETER

The original atomic absorption spectrophotometer relied on a basic principle of atoms that have been heated so that they are in the gaseous state: Atomic vapors emit light at particular wavelengths and also absorb light at some of the same wavelengths. Of those emitted wavelengths of light, one of them will usually be much brighter than all the others. This is called the "peak wavelength," and if a light source is shone through the atomic vapor, the quantity of light absorbed at the peak wavelength will cause the brightness of that wavelength to diminish. Furthermore, the amount of reduction in the brightness of the peak wavelength depends on how many atoms of that element are present in the vaporized sample.

Vaporizing the sample requires a small furnace to burn it. Graphite furnaces that use electrical heating are widely used in contemporary atomic absorption spectrophotometers to vaporize the sample. Alternatively, a solution of the material could be sprayed into the flame to generate the vapor. In this case, organic solvents such as alcohol or heptanes work far better than noncombustible solvents such as water as diluents for samples.

A light source is shone into the atomic vapor, and the best light source is a hollow-cathode lamp. These lamps consist of a quartz or glass envelope with two electrodes, one of which, the cathode, is cup-shaped and composed of several metals. The lamp is filled with a low-pressure noble gas. Application of an electrical current across the electrodes will cause the emission of a particular spectrum of wavelengths of light that will pass through the atomic vapor to the detection machinery of the spectrophotometer.

Atoms at such high temperatures emit light, which can contaminate the light from the lamp that is shone through the atomic vapor to the detector. Therefore, the machine must distinguish between this emitted light and the peak wavelengths emitted from the lamp that is shone through the vapor. Originally, Alan Walsh used a device called a "chopper wheel," which is a circular disk, a third of which is opaque, another third mirrored, and the last third cut away to allow light to pass through. The wheel is located between the cathode lamp and the atomic vapor and rotates as light moves through it. The wheel subtracts some of the wavelengths of light shone through the atoms so that only the peak wavelength hits the atomic vapor. The second feature that solved the light contamination problem was a tuned amplifier that amplified only those peak wavelengths from the light source and extraneous wavelengths emitted by the atomic vapor. Modern devices tend to use a "monochromator," an optical device that selectively transmits only specific wavelengths of light.

Once the light strikes the detector, a photomultiplier generates the desired signal, which passes to an amplifier/rectifier combination, and finally to a recorder, which provides the output. In between the vapor and the detector, a series of lenses precisely bend the light so that it can accurately find its way to the detector.

Walsh's original atomic absorption spectrophotometers were somewhat simple in principle, but they required enormous troubleshooting in order to make them work at optimal efficiency and sensitivity. Improved light sources increased the number of elements the machine could analyze. Improved electronic components improved the sensitivity and accuracy of the machine.

LIFE'S WORK

In January, 1945, Walsh became the chief spectroscopist at the BNF and oversaw all spectrographic research. He developed a technique for detecting impurities in uranium metal. In May, 1946, Walsh immigrated to Australia to work in the Chemical Physics Section of the Division of Industrial Chemistry at the Council for Scientific and Industrial Research (CSIR), which became the Commonwealth Scientific and Industrial Research Organization (CSIRO) in 1949. At CSIR/CSIRO, Walsh experienced a near scientific utopia. Instrumentation in the CSIRO laboratories was state of the art, and bureaucratic red tape was kept to a minimum. Investigators were given tremendous freedom to work on their own, and the atmosphere was highly collegial and collaborative. His first project involved installing the new Perkin-Elmer Model 12B spectrometer. He noted that this machine could not resolve the spectra of larger molecules. Therefore, he designed the "double-pass monochromator" to improve the resolution of the machine, which he patented in 1950.

In March, 1952, Walsh experienced a flash of insight while working in his garden. Chemical analyses at this time were conducted in one of two ways. The first method placed the material under analysis between two discharging electrodes. The light emitted by the material under these conditions provided the means of identifying the elements that composed the material and, by comparison to standard samples, the amount of the elements present in the material as well. A second procedure examined the light given off when a solution of the material was sprayed into a flame. Both procedures were fraught with problems that limited their application. Walsh realized that an atomic vapor absorbs light energy at wavelengths peculiar to its chemical composition. The problem was that a vaporized compound emitted light at the same wavelengths at which it absorbed. However, by detecting the decrease in light emission at the most robust wavelength, an investigator could not only identify the presence of a particular element but also determine the amount of that element present in the sample. The other wavelengths of light emitted by the vaporized material could be eliminated by using amplifiers that were tuned to only the desired wavelength. Walsh went to work the next day and performed a trial experiment with sodium atoms and succeeded. This and other follow-up experiments formed the basis of atomic absorption spectroscopy.

After solving problems and substantially improving his new technique, Walsh filed his final patent specification on October 21, 1954, and published his new technique in 1955 in the journal *Spectrochimica Acta*. The reaction to his work by the scientific community was subdued, since many saw it as a scientific curiosity rather than a practical analytical method. However, an Australian company, Hilger and Watts, entered into an exclusive license agreement with CSIRO to make a commercial atomic absorption machine. Unfortunately, they were unable to produce one that was viable.

In 1958, Walsh was elected a fellow of the Australian Academy of Science. That same year, he was invited to give his first presentation on American soil about atomic absorption spectroscopy. At the Louisiana State University Symposium on Analytical Chemistry, Walsh met spectroscopist James W. Robinson from Esso Research, Baton Rouge. Robinson's excitement about atomic absorption spectroscopy inspired him to collaborate with Walsh. In 1962, Robinson and his colleagues demonstrated that atomic absorption spectroscopy had widespread application in the analysis of most metals and metalloids. This work demonstrated the industrial uses of atomic absorption spectroscopy and the need for commercially produced machines that could effectively use it. Walsh also met a representative from the scientific instrumentation manufacturer Perkin-Elmer. This interaction motivated Perkin-Elmer to form a research group dedicated to developing an atomic absorption instrument in 1960. In 1963, the company shipped its first atomic absorption instrument, the Model 303. This was followed by the Australian company, Tektron, which had collaborated with Walsh and CSIRO since 1958, producing the first Australian atomic absorption instrument in 1964.

During the 1960's and 1970's, Walsh and his collaborators worked to improve atomic absorption instruments and extend their applications to various fields. In 1969, Walsh was elected a fellow of the Royal Society of London. In 1970, he was awarded an honorary doctor of science degree from Monash University, Melbourne. In 1977, Walsh retired from CSIRO, where he had served as chief research scientist and assistant chief of the division. Soon thereafter, Walsh was knighted for his services to science. Even during retirement, he continued to work as an honorary research fellow and a consultant for several years. Walsh died in Melbourne in 1998.

IMPACT

Without a doubt, atomic absorption spectroscopy is the most significant advance in elemental analysis in the twentieth century. With the production of the first atomic absorption machines, chemists had an easy and fast method of determining the presence and concentrations of more than sixty-five of the chemical elements in the periodic table. Furthermore the accuracy and sensitivity of this method drove all "wet-chemical" methods into obsolescence. This method also found applications in fields as diverse as medicine, agriculture, food analysis, mineral exploration, metallurgy, enology, environmental science, forensics, and biochemistry. It is not an overstatement to say that all significant chemistry laboratories in the world possess an atomic absorption spectrophotometer. The use of this technology is universal.

Walsh lived and worked at a time when spectroscopy—the study of the interaction of matter with light—was flourishing. Given the rapid advances in the field, no one would have thought that the field needed a new way of looking at problems. Yet Walsh possessed the rare combination of being brilliant, practical, and exceptionally creative. Even during his years at the BNF, Walsh thought that spectroscopy would not advance much further without "a completely new line of attack." Even though virtually none of his colleagues shared his point of view, Walsh proceeded to gnaw away at the problem until it gave in. The result of his relentless pursuit was a completely new way of determining chemical compositions.

—*Michael A. Buratovich*

FURTHER READING

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Hannaford, Peter. "Alan Walsh 1916-1998." *Historical Records of Australian Science* 13, no. 2 (2000): 179-206. An exhaustive and detailed, but sensitive recollection of Walsh's life, scientific accomplishment, and personal traits.

Robinson, James W. "A Tribute to Sir Alan Walsh—Development of Atomic Absorption in the United States—A Personal View." *Spectrochimica Acta Part B: Atomic Spectroscopy* 54, no. 14 (December, 1999): 1993-1998. A personal encomium of Walsh by an accomplished spectroscopist who knew Walsh personally and collaborated with him.

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Willis, John B. "The Early Days of Atomic Absorption Spectrometry in Clinical Chemistry." *Spectrochimica Acta Part B: Atomic Spectroscopy* 54, no. 14 (December, 1999): 1971-1975. A colleague of Walsh tells some very entertaining stories about the development of atomic absorption spectroscopy and highlights the trial-and-error nature of science.

See also: Robert Wilhelm Bunsen; Sir William Crookes; Dennis Gabor; Ali Javan; Dimitry Ivanovich Mendeleyev.

ERNEST THOMAS SINTON WALTON

Irish physicist

Walton, working with John Cockroft in Ernest Rutherford's laboratory at Cambridge University, built the first high-energy particle accelerator and with it produced the first human-made nuclear reaction.

Born: October 6, 1903; Dungarvan, County Waterford, Ireland
Died: June 25, 1995; Belfast, Northern Ireland
Primary field: Physics
Primary invention: Cockroft-Walton particle accelerator

EARLY LIFE

Ernest Thomas Sinton Walton was born in Dungarvin in the county of Waterford, Ireland, on October 6, 1903. His father, the Reverend John Walton, was a Methodist minister from County Tipperary. The Irish church frequently moved its clergy from one parish to another, so Ernest attended a number of different elementary schools. When he was older, he was sent to boarding school in Belfast, where he became an outstanding student. He was passionate in his studies of science and mathematics and especially liked to build things. He carried a toolbox with him and became proficient at using the tools.

After his studies in Belfast, Walton moved to Trinity College in Dublin and graduated in 1926 with firsts in mathematics and science. He stayed on at Trinity to work toward a master's degree and was given the problem of explaining why a liquid moving past a cylinder creates twin groups of vortices in the liquid. Walton designed and built apparatuses to study this phenomenon and was able to photograph the whirlpools as they were formed. He was awarded his master's degree in 1927.

The most exciting area in physics at the time was the study of the atomic nucleus, and the place to study this was the Cavendish Laboratory in Cambridge under Ernest Rutherford. Walton seized the opportunity of a scholarship mainly reserved for students from the Dominions and moved to Cambridge in October, 1927, to work toward a Ph.D. in Rutherford's laboratory.

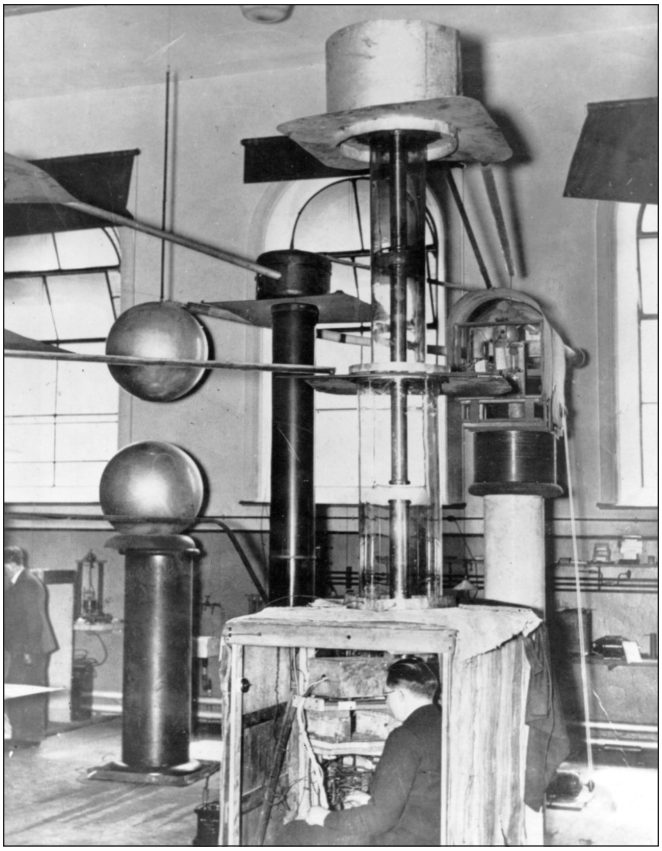
LIFE'S WORK

Walton's mechanical abilities were immediately recognized by Rutherford, and Walton was given a project to build a device that would accelerate protons to high enough energies to overcome the repulsion of the positively charged nucleus and penetrate within. Rutherford had discovered in 1911 that the atom had a heavy positively charged nucleus surrounded by electrons. His experiments were done with alpha particles from a radioactive source, but he recognized that to study inside the nucleus would require more intense beams of smaller charged particles such as protons. The Russian scientist George Gamow, using the new wave mechanics, had calculated that protons with energies of 300,000 electronvolts (300 kiloelectronvolts) would be sufficient to overcome the charge on the nucleus of light elements and produce transmutations in the nucleus.

Walton's first two attempts to build a proton accelerator were failures. He first tried to build an accelerator similar to a transformer, in which protons in an evacuated chamber between the poles of a magnet would be accelerated by an increasing magnetic field. He was never able to obtain a focused beam by this method, so he tried a linear accelerator in which the protons would be accelerated down a long vacuum tube by a series of electrodes, each of which give a kick to the protons and increase their energy. This device also failed to give a measurable beam, because the protons were lost in the walls of the beam tube.

Walton was persistent and would not give up the problem. He had heard of a voltage-doubler circuit that used current rectifiers and capacitors to turn alternating current from a transformer into direct current at twice the voltage of the output of the transformer. He thought that, by putting a number of these voltage doublers together, he could obtain high enough direct-current voltages to accelerate protons that could probe into the nucleus.

Most of the experiments in physics research of the time were done with desktop equipment that could be made in a small machine shop. The accelerator that would be necessary to study the interior of the nucleus would be a much larger undertaking requiring an entire room and the expenditure of considerable money and effort. Rutherford approved Walton's plans and found a room in the basement of the laboratory that was large enough to build the high-voltage machine safely.



The Cockroft-Walton accelerator, used by Ernest Thomas Sinton Walton and his colleague John Cockroft at the Cavendish Laboratory at Cambridge University. The men were awarded the 1951 Nobel Prize in Physics for their atomic research. (Getty Images)

To build the accelerator, Walton teamed up with John Cockroft, a physicist with a background in electrical engineering who had stayed on at the Cavendish Laboratory after his Ph.D. and become interested in nuclear transmutation. Together they designed an accelerator that rectified and multiplied the output of a transformer four times to obtain a steady voltage of 800,000 volts. This was used to accelerate protons from a discharge in hydrogen at the top of the machine into an evacuated glass cylinder and unto a target.

By April, 1932, they had constructed the accelerator and were ready for the first experiment. They sealed a thin target of lithium inside the accelerator tube at 45° to the beam and a thin mica window on the side of the tube. With a potential of 125,000 volts, scintillations were seen outside the mica window. After various other experiments, the scintillations were seen to be due to alpha particles from the breakup of the lithium nuclei. This was widely reported by the press and became a worldwide sensation. The accelerator immediately became an important tool for studying the nucleus and was widely copied around the world.

After the glory days of the early 1930's, the young men who had made the nuclear revolution began to drift away from the Cavendish Laboratory to other organizations. Walton was offered a fellowship by his old college and returned to his roots in Trinity College in Dublin. He knew that there would be little money for research but believed that the most important contribution he could make would be to encourage and support science in Ireland. Although he attempted to do further nuclear research when money for equipment could be obtained, his primary successes were in teaching. His lectures were known for their clarity, and his laboratory demonstrations caught the imagination of his students.

During World War II, Walton was asked by Sir James

THE COCKROFT-WALTON ACCELERATOR

Ernest Thomas Sinton Walton and his colleague John Cockroft were the first to build a charged-particle accelerator with enough energy to penetrate into the atomic nucleus. Although other types of accelerators quickly followed with higher energies, the advantages of simplicity of the technology and precision of the energy obtainable make the electrostatic machine of Walton and Cockroft useful to the present day.

The basic invention that made the Cockroft-Walton accelerator possible was the voltage-multiplier circuit that takes alternating current from a transformer and converts it into direct current at much higher voltage. The voltage multiplier is an arrangement of rectifiers that allow current to pass in only one direction with capacitors that are in series to obtain the high voltage.

The positive output of the voltage multiplier was attached to the top of an evacuated column where hydrogen ions (protons) were produced. The positively charged protons were repelled by the high positive voltage at the top of the column and accelerated down the tube into the target area.

Cockroft and Walton built their accelerator to study the nucleus. The accelerator's first use was to split a lithium nucleus into two alpha particles. Because of the breakdown of air at high voltages, this type of accelerator is limited to about 2 million electronvolts, but there continue to be many nuclear studies at lower energies where the Cockroft-Walton accelerator excels. In addition, these accelerators continue to be used as preaccelerators for injection of protons into the huge accelerators at the Fermi National Accelerator Laboratory in Illinois and the European Organization for Nuclear Research (known as CERN) near Geneva, Switzerland.

The voltage-multiplier circuit invented by Cockroft and Walton is used in many other applications in the home and industry, where it is necessary to convert alternating current at low voltage into high-voltage direct current. Industry uses a Cockroft-Walton-type accelerator to implant ions into semiconductors to manufacture the chips widely used today. Any home that has a TV or a computer cathode-ray-tube monitor makes use of a voltage multiplier to obtain the high-voltage direct current needed.

Chadwick, head of the British contingent in the Manhattan Project, to join what he described as war work in the United States. Walton declined because he felt an obligation to Trinity College, where there would be only two professors left to teach physics if he left.

In 1946, Walton was made Erasmus Smith's Professor of Natural and Experimental Philosophy, and he spent the rest of his career at Trinity College. Even after his retirement in 1974, he was part of the college and attended seminars and Physics Department teas to keep in touch with the students.

Walton received many honors during his career, the first being the Hughes Medal of the Royal Society of London with Cockroft in 1938. He and Cockroft were awarded the Nobel Prize in Physics in 1951 for their "work on the transmutation of atomic nuclei by artificially accelerated atomic particles." After his retirement, Walton also received many honorary degrees from both British and American institutions.

He had a long happy marriage with his wife, Freda, whom he had married in 1934 after his successes at the Cavendish Laboratory. They had five children, several of whom followed in their father's footsteps and became physicists. Walton lived until the age of ninety-one and died in Belfast in 1995.

IMPACT

Walton and Cockroft were able to show with their accelerator that charged-particle beams could be produced with specific controlled energies and at much higher intensity than the radioactive sources that were used for nuclear research at the time. They were the first to show that quantum tunneling into the nucleus as predicted by the new wave mechanics occurred, and their measurements of the energy of the alpha particles produced by the splitting of lithium verified Albert Einstein's mass-energy relation, $E = mc^2$.

The Cockroft-Walton accelerator had an immediate and profound effect on nuclear research. It was the first of the thousands of accelerators to study the interior of the atom. It was also the first accelerator to show that an atomic nucleus could be split by human-made high-energy charged particles. It and other accelerators that followed galvanized the study of nuclear physics, and within a year hundreds of physicists had switched to the study of the nucleus. Within five years, 30 percent of the articles in the leading American physics journal, *Physical Review*, were devoted to research in nuclear physics.

A Cockroft-Walton accelerator was used in World War II as part of the research leading to the atomic bomb, and it was later used to study nuclear reactions occurring in the Sun and stars. In recent years, the Cockroft-Walton accelerator's primary use in physics research is as a preaccelerator to inject charged particles into the higher-energy machines used to study the particles and forces within the nucleus.

Voltage multipliers of the type pioneered by Cockroft and Walton are now used for many other applications besides nuclear physics research. They are used in the high-voltage power supplies in electron microscopes, X-ray systems, air ionizers, television sets, bug zappers, and many other applications that require high-voltage direct current.

—*Raymond D. Cooper*

Further Reading

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Crowther, J. G. *The Cavendish Laboratory, 1874-1974*. New York: Science History Publications, 1974. A comprehensive history of the first one hundred years of one of the greatest scientific laboratories in the world. It was here that Rutherford and his students first began the study of the nucleus of the atom. Illustrations, references, index.

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See also: Albert Einstein; Enrico Fermi; Hans Geiger; M. Stanley Livingston; J. Robert Oppenheimer; Edward Teller.

An Wang

Chinese American electrical engineer

Wang invented the magnetic memory device that dominated the storage capacity of computers for twenty years, until the development of semiconductor technology. He became a major American entrepreneur in the area of calculators, word processors, and computers.

Born: February 7, 1920; Shanghai, China
Died: March 24, 1990; Boston, Massachusetts
Primary fields: Computer science; physics
Primary invention: Pulse transfer controlling device

Early Life

An Wang's parents named their son with an expression meaning "peaceful king." His father taught English in an elementary school and was a firm disciplinarian. His mother was far less strict and very loving. Wang lived either in Shanghai or Kun San, where his father taught, until the age of twenty-one. A very bright boy, Wang began school in the third grade at the age of six. Although he was very proficient in mathematics, he did less well in other subjects, which were taught by rote memorization. In many ways, his curriculum was like that American students confronted at the time, and since some of the textbooks were written in English, he was faced with the challenge of learning English as well. Outside school, he learned much about Chinese thought and literature from his grandmother, who also introduced him to the philosophy of Confucius.

As he progressed in his education, Wang spent much time reading about scientific thinkers such as Leonardo da Vinci, Galileo, and Sir Isaac Newton. He attended Shanghai Provincial High School (which had an eminent reputation), graduated at sixteen, and entered an excellent college, Chiao Tung University, also in Shanghai, where he studied electrical engineering. He also edited a scientific digest compiled by students at the university. During these years of the 1930's, Japan increased military pressure on China and in 1937 began to occupy its territory. By November of that year, the Chinese army had been driven out of the Shanghai area. When Wang graduated as valedictorian (1940), he stated that there was war "all around him."

LIFE'S WORK

After a year as a teaching assistant in electrical engineering at Chiao Tung, Wang took a job building transmitters and radios, which the government could use in the war effort. This work had to be done hundreds of miles inland from Shanghai in Kweilin. In World War II, his parents died in ways unknown to him, and although his sisters and brothers survived the war, he did not see any of them again for forty years.

In 1945, Wang took advantage of a program that was sending well-trained Chinese engineers to the United States. The goal of the Chinese government was to allow particularly talented young engineers to learn American technology and help rebuild postwar China. Wang entered Harvard University and in 1948 completed the requirements for a Ph.D. in applied physics. He decided not to return to China but to work in the United States.

The experience that led to his later achievements was his work at the Harvard Computation Laboratories. At the time, he was thinking of this work not as a step in computing but as a job that he needed as a husband and father, for in 1949 he married Lorraine Chu, and within a few years they had three children. At a time when computer technology was just beginning to develop, Wang began to work on the problem of storing information in a computer. At that time, it was understood that computers would use a binary system containing only two digits rather than the usual ten digits. The speed of a computer depended on how fast the circuit could change from one digit, the 1, to the other, the 0. Working on the problem of how to design a means by which computers would have rapid access to data, Wang found that there were several possible types of storage of information. Magnetism seemed to offer the best solution. He decided that he had to find a way to read and store information without mechanical motion, which slowed the process.

Having progressed in his effort, Wang decided to leave Harvard and form Wang Laboratories in 1951 in Boston. Despite its plural name, his business was first established over a garage in Boston's South End. He began the business with capital of $600, no orders, no contracts, and no office furniture. His business grew when he was able to convince scientists that he could design applications that would facilitate their work. One of his customers was International Business Machines (IBM); after a series of difficult negotiations, he assigned a patent to IBM for $500,000. Wang also developed his own line of products, one of which was Linasec (1963), a semiautomatic typewriter. Wang's company was now becoming important. His LOCI desk calculator, introduced in 1964, not only could do ordinary mathematical problems but also could quickly generate exponential values. Scientists and engineers, who until that time had to rely on a mainframe computer, could now work from their office desks.

Wang's word-processing machine, in-

THE PULSE TRANSFER CONTROLLING DEVICE

The most important of An Wang's forty inventions was what he called in his patent a "pulse transfer controlling device." It established a way to record and read magnetically stored information without mechanical motion and thus enormously increased the speed of operation. The information could be stored without mechanical motion by magnetizing material in either a positive or negative magnetic direction.

Wang's invention is based on a magnetic core, which was an arrangement of iron rings connected by wires. Every memory operation requires a recording cycle and a reading cycle. The transfer of information could be controlled by setting the core at a state of residual magnetic flux density that would either allow or prevent the transfer. If a negative pulse is applied to a winding on such a core, there will be little or no flux change at the core and no power will be transferred. At a positive state of residual magnetism, a large change will occur and power will be transferred to the core.

The problem in reading such a text was that it reversed the direction of the flux and destroyed the information that it stored. The insight that allowed Wang to develop the memory core was his realization that the information could be rewritten immediately afterward, a process that would take only a few thousandths of a second. The polarity of the residual magnetism of the core could be controlled to a desirable state by applying a pulse. For the core to operate efficiently, the rings had to be very small. At high speeds, the wires of the core could heat up, their resistances could change, and the drive currents could fluctuate and cause internal interference. The cores were first assembled by hand, but the demand for smallness eventually made hand assembly too difficult. Machines were developed that could knit the core rings together.

Wang's invention became the basis for all high-speed computer memory. Using core memory, Wang Laboratories became an important manufacturer of early desktop computers. Wang's core memory continued to serve as the basis for information storage in computers until the development of solid-state memory began to replace it in the 1970's.

vented in 1971, sparked the development of a word-processing system in 1976. His word-processing system had its own microprocessor and the capacity to function as part of a network; thus, Wang was one of the early developers of a local area network (LAN), which could bring users together to share documents and applications. In two years, Wang Laboratories was the largest maker of stand-alone word processors in the world. These word processors for science, business, and industry anticipated their later use by the millions of people with access to personal computers.

Successful as Wang Laboratories were in the 1970's, the firm began to encounter the problems peculiar to a proprietary business that had grown into a large company. By 1981, Wang had surrendered his ruling function to a management committee. His son Frederick and John F. Cunningham were named vice presidents. Two years later, Cunningham was named president and chief operating officer. A drop in earnings the next year resulted in layoffs of workers and other types of cost reduction. Cunningham resigned, and Wang again took charge of the company. Soon, however, Frederick Wang was named its president, and Wang Laboratories declined in the late 1980's.

Wang held forty patents and received twenty-three honorary degrees. He was named a member of the National Inventors Hall of Fame. He also made his mark as a philanthropist. He donated handsomely to Boston's Performing Arts Center, to Harvard University, and to Wellesley College, and he created the Wang Institute of Graduate Studies, partly intended to benefit China scholars. He died in 1990.

IMPACT

From a tiny operation, Wang Laboratories grew to an organization employing thirty thousand people. Wang's work advanced the development of computers for use by the government, science, business, and eventually private citizens. When Wang began his work, computers capable of doing the work now done routinely by mere laptops had to be mainframes, which were too large and expensive to be used by any offices or businesses of ordinary size. His development of magnetic core memory made desk-sized calculators possible, and after other scientists developed solid-state technology, he applied it to the production of minicomputers and word processors. Wang Laboratories became a leader in word processing in the 1970's.

Wang's accomplishments as an inventor encouraged other Asian Americans and thus enlarged the ranks of the men and women in technological invention. He designed many technological applications for fellow scientists and established an important link between engineering science and industry. These applications ranged widely. As modified by Jay Wright Forrester at the Massachusetts Institute of Technology, Wang's core memory design was used by the U.S. Air Force to control flight simulation. Wang benefited the newspaper industry by designing the first electronic typesetter system. Another design resulted in the electronic scoreboard in Shea Stadium, the home of the New York Mets baseball team.

Wang's development of the largest minority-owned business in the United States proved that the Horatio Alger success story—in which vision, energy, determination, and the courage to compete with larger and richer operations (in his case, IBM) could raise a person to prominence—was possible. Wang's philanthropy also contributed to educational and cultural activities for many people, particularly in the Boston area.

—*Robert P. Ellis*

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See also: Jay Wright Forrester; Jack St. Clair Kilby.

TAYLOR GUNJIN WANG

Chinese American physicist

Wang's inventions moved from novel methods of acoustic manipulation of matter to the design of new encapsulations for cells used in bioengineering, with practical applications in the fight of diseases such as diabetes. His innovative design of drop dynamics experiments in zero gravity made him the first Chinese American astronaut.

Born: June 16, 1940; Shanghai, China
Also known as: Taylor Gun-Jin Wang; Wang Ganjun (Pinyin)
Primary fields: Biology; medicine and medical technology; physics
Primary invention: Cell encapsulation

EARLY LIFE

Taylor Gunjin Wang (wahng) was born in Shanghai, China, during World War II. He was the oldest son of businessman Zhang Wang and his wife, homemaker Jiehong Yu. His parents would have two more boys and one girl. In 1943, the Wang family fled from the Japanese invaders to the seat of the Chinese nationalist government in Chongqing. At age three, Wang fell into the raging Jialing River. Clinging to a bamboo pole, he was saved from drowning. His family interpreted his survival as a sign that his life would be special.

Wang's family returned to Shanghai at the end of World War II in 1945. Wang's first boyhood experiment involved winding up a valuable mantel clock beyond breaking point. He did this to try to find out if time passed faster if the clock was wound up more than usual. His inquisitive spirit never left him.

After their father fled to Taiwan when the communists conquered mainland China in 1949 and their mother was able to join him there in the same year, Wang and his siblings sought to escape to Hong Kong in 1950. The smuggler hired to pass the four children beyond communist lines was ready to betray them at the border. However, a kindly English journalist intervened and saved them from communist border guards. The Wang family was reunited in Taiwan in 1950.

At age twelve, Wang decided to become a scientist. This was against the wishes of his father, who wanted Wang to inherit the family business. In 1961, Wang graduated from the Affiliated Senior High School of National Taiwan Normal University in Taipei. He assumed that his intelligence alone would ensure him entrance to a Taiwanese university. Surprisingly, as he neglected diligent study, he failed the Taiwan college entrance exams. Dedicating himself to his studies during two years in Hong Kong, in 1963 Wang was admitted to the University of California, Los Angeles (UCLA), and moved to the United States. There Wang married Xueping Feng in 1965, and their first son, Kenneth, was born the next year.

LIFE'S WORK

In 1967, Wang graduated from UCLA with a bachelor of science degree in physics. He obtained his master of science degree in physics from UCLA in 1968, focusing on fluid mechanics. In 1970, Wang's second son, Eric, was born. Wang obtained his Ph.D. in physics from UCLA in 1971; his thesis was on solid-state physics.

In 1972, Wang was appointed senior scientist in the Physics Section of the Jet Propulsion Laboratory (JPL) at Pasadena's California Institute of Technology. His research on fluid dynamics of drops and bubbles in a containerless environment attracted the attention of the National Aeronautics and Space Administration (NASA). NASA accepted one of Wang's proposed space experiments in 1974. He became a U.S. citizen the following year. On October 4, 1977, Wang's first patent was granted. It was for an invention in acoustic energy shaping, discovered by Wang and two other scientists.

In 1979, Wang became manager of the Microgravity Science and Applications Program at JPL. In 1982, NASA began to look for astronaut-scientists to conduct experiments in space. Since Wang's research on the dynamics of drops and bubbles in microgravity (an almost weightless environment) was very suited for space research, he applied for the program. Against considerable competition, Wang was chosen as a payload specialist astronaut on June 5, 1983.

On April 29, 1985, Wang lifted off on the STS-51-B *Challenger* space shuttle flight, which lasted until May 6. Wang spent seven days and eight minutes in space. Wang was principal investigator of the Spacelab 3 drop dynamics experiments. Mortified when his first experiment failed on the second day of the mission, he pleaded with NASA bureaucrats to give him extra time to fix his setup despite an ultratight time schedule. When NASA refused, he threatened not to return to Earth, alarming mission control. Supported by his fellow astronauts, he was finally given extra time. Wang repaired his experiments' compartment and successfully finished his research. In addition to contributing to pure science, his space experiments had positive implications for finding a cure for diabetes.

Upon his return to Earth as the first ethnic Chinese astronaut, Wang was awarded the NASA Space Flight Medal and celebrated the Taylor G. Wang Recognition Day on October 11, 1985, in Washington, D.C. Many more public awards followed.

In 1988, Wang became Centennial Professor of Materials Science and Engineering at Vanderbilt University in Nashville, Tennessee, and the director of the Center for Microgravity Research and Applications. His research and subsequent patents for his inventions focused on drop dynamics in containerless environments. In 1992, Wang's experiments for drops in zero gravity were carried out by scientists aboard the space shuttle carrying the U.S. Microgravity Laboratory 1. In 1993, Wang was appointed director of the Applied Physics Program at Vanderbilt. In 1995, Wang's experiments in designing encapsulations for living cells were performed in the space shuttle's U.S. Microgravity Laboratory 2.

Over the next years, Wang's inventions gradually moved from the field of pure physics to applications in bioengineering. Wang focused on ways to create stable shells for cells, embedded in drops that could carry capsules with beneficial islets to combat the disease of diabetes. The primary challenge was to create custom-designed capsules that protected the cells inside them and that did not trigger a body's immune system to attack and destroy them. Here, Wang's inventions yielded him three more patents, granted in 1995-1996. An application for a patent for his invention of a multimembrane immunoisolation system for cellular transplants was filed in 2006. A patent for capsule patches for cellular transplantation without immunosuppression was filed in 2008.

Wang continued to teach and conduct research at Vanderbilt University and did not plan to retire until his experiments were finished successfully. He continued to work on inventing new designer capsules for cells that can deliver their beneficial content to a diabetes patient without causing the body's immune system to destroy them before their healing mission is accomplished.

CELL ENCAPSULATION

Taylor Gunjin Wang's encapsulation system for the immunoisolation of living cells was discovered with five other scientists on his research team. The system enabled the customized creation of protective capsules for cells that carry beneficial hormones and proteins that they release when transplanted into the body of a patient suffering a disease resulting from a deficiency of certain hormones or proteins, as is the case with diabetes. The problem Wang faced was that a host's body immune system fights transplanted cells and quickly destroys them unless the immune system is suppressed, which results in many negative side effects. Before Wang's invention, the capsules used to immunoprotect cells could not be customized and optimized for specific applications and were of limited practicability.

Wang's novel encapsulation system creates a new multicomponent polymer capsule that permits individual modification of its size, the thickness of its wall, its mechanical strength, its two-way permeability, and a variety of its surface characteristics. With Wang's system, cells with beneficial content can be put into customized capsules in which they are transplanted into the diseased body. Such encapsulated cells are not rejected by the host's immune system, and because of their specific design, the capsules optimize the inflow of molecules that the beneficial living cell inside needs to survive and function. The outflow of the desired beneficial cellular products, such as specific hormones or proteins, can be fine-tuned for each case and application.

Wang and his team analyzed more than one thousand different chemical combinations of polyanions and polycations to create working capsules. Only thirty-three combinations were discovered to work as desired. These capsules consist of a special mix of agents—namely, high-viscosity sodium alginate, cellulose sulfate, and a polycation. The capsules are created in a novel reactor that allows for customization of the cells by carefully altering the ingredients of the eventual combination.

In their first practical application, Wang's capsules carried beneficial cells that consisted of rat pancreatic islets that emitted cellular products that reversed and cured the diabetes of living mice. Eventually, Wang's capsules may carry beneficial cells to cure diabetes and other diseases in human patients. His invention falls in the fields of endocrinology, protein chemistry, and biomedical engineering. His work is an example of how physics can aid medical advances.

IMPACT

Wang has been an outstanding scientist who realized early that experiments in space could contribute greatly to new knowledge and inventions in his field of fluid mechanics and solid-state physics. He was a visionary who designed new experiments leading to new knowledge when successfully carried out aboard the space shuttle. His personal courage and determination to become an astronaut-scientist added adventure to his endeavors as physicist. He inspired many young people both to embark on a scientific career and to participate in space exploration. He has been awarded many prizes for his contributions as scientist, inventor, and citizen. In 2007, Wang was honored as a White House state ceremony participant and received the Distinguished Science and Technology Award at the Asian American Engineer of the Year Award ceremony of the National Engineers Week Foundation.

Once Wang invented new ways of engineering customized capsules for cells transported in drops and bubbles, he successfully joined his research in pure physics to the field of bioengineering. He sought to ensure that his capsules were useful in future medicine and contributed to the fight against diabetes. His work came to stand at the nexus of physics and medicine.

By 2008, Wang held twenty-six patents and had two more in the application process. By that time, he had authored one book, edited another, contributed four textbook chapters, and published more than two hundred scientific articles that contributed greatly to the understanding of the mechanics of drops and bubbles in a microgravity environment and novel protective cell capsules.

—R. C. Lutz

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See also: Georg von Békésy; Wilson Greatbatch; Mary-Claire King; René-Théophile-Hyacinthe Laënnec; Naomi L. Nakao; Jonas Salk.

FELIX WANKEL

German mechanical engineer

Wankel was an imaginative, self-trained engineer and inventor whose most memorable contribution was the development of the rotary engine that bears his name—the Wankel engine—and operates by using orbiting triangular rotors that function much as pistons do in conventional gas-powered engines.

Born: August 13, 1902; Lahr, Germany
Died: October 9, 1988; Lindau, West Germany (now in Germany)
Primary fields: Automotive technology; mechanical engineering
Primary invention: Wankel rotary engine

EARLY LIFE

Felix Wankel (FEE-lihks WAHN-kuhl) was born in the Upper Rhine River Valley in the Swabian town of Lahr. Lahr is close to Stuttgart, the home of such automobile companies as Daimler and Benz. Wankel first conceived the idea of the rotary engine that bears his name when he was twenty-two years old.

The young man's father, Rudolf Wankel, died in World War I, leaving Felix's widowed mother, Martha, with few financial resources. Felix was twelve when his father died. What limited income his mother had was soon wiped out by Germany's staggering inflation during the 1920's. There was no possibility for her only son, a withdrawn and reclusive youth, to pursue a university education or enter into an apprenticeship. When Felix did attend school, he was bored by it. His active mind moved more rapidly than the minds of his classmates and teachers.

Inherently curious and mechanically gifted, Felix learned a great deal about technology by studying on his own. Out of his well-disciplined program of self-education came his earliest realization that rotors could replace pistons in engines, thereby reducing their size and weight while decreasing their manufacturing cost and substantially increasing their reliability. Such engines, seldom requiring repairs and needing only routine maintenance, delivered a remarkably smooth performance.

Most automotive engineers in the mid-1930's, nearly all of them with more impressive academic credentials than Wankel, were convinced that the conventional reciprocating engine was the most desirable source of power for motor vehicles. Wankel was not convinced, and he quietly went about experimenting with alternative power sources that resulted in his development of the rotary engine.

Pressed to support himself and his mother, Felix, in 1921, took a job in a bookstore in the university town of Heidelberg, where his main responsibility was scientific publications. When he developed a kidney condition, the bookstore's management transferred him from the printing room, where high concentrations of lead were affecting his health, to the storeroom, which he quickly reorganized to make it more efficient.

LIFE'S WORK

During the three years that he spent working in the bookstore in Heidelberg, Felix found ample time to read the scientific sources that were his chief responsibility. He also attended night school and took correspondence courses to help build his knowledge base in the scientific

Felix Wankel with his rotary engine, an alternative to the conventional piston-driven engine. (Popperfoto/Getty Images)

Wankel's Rotary Engine

Felix Wankel's rotary engine is housed in a uniquely shaped combustion chamber of an automotive engine, its triangular rotor replacing the pistons that are characteristic of most internal combustion engines. The stages through which the rotor passes are, respectively, intake, compression, expansion, and exhaust.

During the intake stage, air is taken in and mixed with fuel that is drawn into the motor through the tiny intake opening. In the next stage, the rotor compresses the mixture of fuel and air as the rotor passes the intake opening. During the next stage, a spark plug ignites the mixture, which causes the burning gases to expand. This, in turn, causes the rotor to move around the output shaft. Finally, the burnt gases are expelled through the exhaust port as soon as the rotor tip uncovers it. When this four-stage cycle has been completed, it automatically repeats itself, resulting in a smooth infusion of power into the engine.

The most important parts of the rotary engine is the triangular rotor and the uniquely shaped chamber in which it rotates. The tips of the rotor are in continuous contact with the chamber's walls and, because of the rotor's triangular structure, separate the chamber into three specific areas. In the four-stroke cycle gasoline engine, each piston has to move back and forth two times and stop four times to go through its cycle. The rotary engine, on the other hand, operates continuously, completing three cycles of combustion with each complete rotation of its rotor. The single-rotor engine produces one power stroke for each turn of its output shaft, whereas the more conventional piston engine produces one power stroke every time the piston moves down its cylinder. Thus, the dual-rotor engine is able to generate a number of power strokes equal to that of a four-cylinder piston engine.

Because all the motion in a Wankel engine is rotary, its operation is remarkably efficient. Whereas in the piston engine the reciprocating vertical motion has to be converted to rotary motion, in the Wankel engine there is no need for such a conversion. Every revolution of the rotor results in three impelling power forces.

areas that most interested him. In 1924, he first conceived the notion of an engine whose pistons would be replaced by rotors, and he embarked intermittently on the work that would become his lifelong passion and would result in his invention of the Wankel rotary engine.

Clearly possessed of a unique intelligence—some of the people who knew him well called it genius—Wankel approached inventing with a childlike excitement. Once he had overcome the basic obstacles lying in the path of his research, however, rather than pursuing it to the end, he tended to abandon it in order to turn to other projects that excited him. In 1927, Wankel became a partner in an engineering company and soon afterward opened his own research laboratory, in which he engaged in considerable experimentation on internal combustion engines, but with special emphasis on the rotary engine. This experimentation lasted well into the 1930's.

In early 1933, Adolf Hitler was elected chancellor of Germany. Soon afterward, Wankel, who was an outspoken opponent of Hitler, was imprisoned for several months because of what the German government considered his subversive political views. Upon his release, with World War II looming ominously in the future, Wankel's expertise was needed as Germany prepared for war. He was employed by the German Air Ministry to develop seals and rotary valves for the Luftwaffe, the German air force. He also worked for the German navy on developing seals and valves for torpedoes. Between 1936 and 1945, he worked for the Deutsche Versuchsanstalt für Luft-fahrt (DVL), the German aeronautical research establishment, on developing rotary valves. When the war ended in 1945, the occupying Allied forces imprisoned Wankel for several months, forcing him to close his laboratory. The Allies in charge of his imprisonment confiscated his scientific work and ordered him to discontinue his experiments.

Unable to pursue his interest in the rotary engine for several years, Wankel was finally employed in 1951 by the NSU Motorenwerke AG to continue his work on developing a rotary engine, which NSU hoped to use in manufacturing its motorcycles. Wankel completed the first design for a rotary-piston engine in 1954 and, on February 11, 1957, completed the first prototype of his rotary engine that turned in slightly over twenty horsepower.

Wankel continued to refine this engine for Kreiskolbenmotor (KKM) AG. In July, 1958, he tested his new and improved engine. By now, considerable interest had develop worldwide for the innovations that Wankel had created. In 1967, the Japanese automobile maker Mazda introduced the Cosmo Sport, one of the world's first dual-rotor rotary engine cars. The company manufactured many rotary engine sports cars that were much in demand because of their dependable power and the infrequency with which they required repairs. Many such vehicles are still in use. In 1978, Japan manufactured the Mazda RX-7 largely for distribution in the United States.

On December 5, 1969, in recognition of his singular contributions to the field of automotive engineering, Wankel was awarded an honorary doctorate in engineering by the Technische Universität München. Ever reclusive, Wankel continued to reside in the Swabian area of Germany in which he was born and raised. He developed a private testing facility and laboratory there. Even as his long life inched toward its end, he spent a great deal of time working in his laboratory, which he named The Institute. Despite his monumental contributions to automotive engineering, it is said that he never obtained a driver's license for himself. He died in Lindau, West Germany, at the age of eighty-six.

IMPACT

In 1957, shortly after Wankel unveiled the prototype of his rotary engine, automobile manufacturers throughout the world and particularly in Japan and the United States became extremely interested in this new approach to powering vehicular engines, most notably those used to power automobiles, trucks, and motorcycles.

Rotary engine automobiles, like piston engine automobiles, require a battery, a starter motor, and a distributor to engage the engine. They also require cooling and lubrication systems to make their engines work efficiently. To this extent, they are similar to automobiles with more conventional engines. One of the major selling points of the Wankel rotary engine is that it has less than half the moving parts of conventional piston engines, meaning that there are fewer parts that can malfunction.

Despite the obvious virtues of rotary engines, they came on the market at an unfortunate time. In 1971, there was an international energy crisis that discouraged people from purchasing vehicles whose energy efficiency was questionable. The early enthusiastic celebrity that the Mazda vehicles had evoked soon cooled as the American economy took a downturn. Nevertheless, Mazda continued to experiment with the rotary engine and to refine it in many ways. By the end of the 1970's, the Japanese manufacturer concentrated on producing sports cars with rotary engines for European and American markets, where such sports cars were received enthusiastically. Mazda ran an extensive advertising campaign for its RX-7, released in 1978, and buyers flocked to showrooms to learn more about this innovative automobile that promised sustained, trouble-free operation.

—*R. Baird Shuman*

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Dark, Harris Edward. *The Wankel Rotary Engine: Introduction and Guide*. Bloomington: Indiana University Press, 1974. Perhaps the best overall presentation of details about the Wankel rotary engine, profuse with illustrations and detailed in its discussion of this revolutionary development in automotive propulsion.

Faith, Nicholas. *The Wankel Engine: A Story of the Revolutionary Rotary Engine*. London: Allen & Unwin, 1976. A comprehensive overview of the invention and development of the rotary engine as advanced by Felix Wankel. The presentation becomes somewhat technical but is nevertheless generally clear and direct. Enhanced by valuable illustrations.

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; John Boyd Dunlop; Henry Ford; Charles Goodyear; Charles F. Kettering; Étienne Lenoir; Hiram Percy Maxim; André and Édouard Michelin; Ransom Eli Olds; Nikolaus August Otto; Stanford Ovshinsky; Sylvester Roper; Ignaz Schwinn; Alexander Winton.

LEWIS WATERMAN

American insurance broker

Waterman invented the first leak-proof fountain pen that could be relied on to perform properly. He founded the L. E. Waterman Company, which set the standard for quality pens and was instrumental in creating the market for fountain pens.

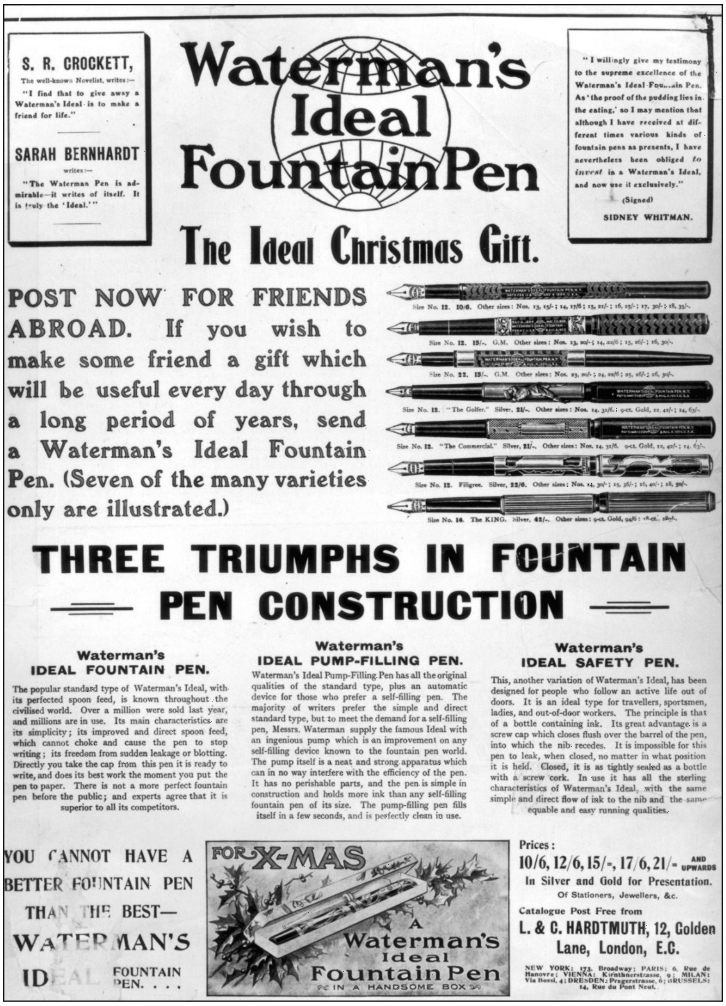
Born: November 20, 1837; Decatur, New York
Died: May 1, 1901; New York, New York
Also known as: Lewis Edson Waterman (full name)
Primary fields: Business management; household products
Primary invention: Waterman fountain pen

EARLY LIFE

Lewis Edson Waterman was born in Decatur, New York, on November 20, 1837. He grew up on a farm and had a number of jobs before he invented his capillary feed fountain pen. The facts of his life during this period remain somewhat enigmatic. Waterman himself told different stories about his work during this time. He apparently taught school for a year or two, worked as a book agent for some ten years, and then worked as a life insurance agent for about fifteen years. He was also employed at one time by the *Railroad Gazette* and a trade publication, *National Car Builder*.

The commonly told story of what brought about his invention of the leak-proof fountain pen is generally considered a fabricated tale. According to the story, Waterman was working as an insurance broker, meeting with a client who was to sign a very lucrative contract with him. Waterman supposedly bought a new fountain pen for the client to use to sign the contract. The signing turned into a disaster when the pen leaked ink all over the contract. From this point, the story has two conclusions. One states that the client interpreted this as an ill omen and refused to sign the contract. The second ending recounts that Waterman hurried off to get another contract and upon his return found that the client had signed with another agent. Some versions of the story also state that Waterman went to his brother's farm in upstate New York and invented his innovative ink feed, which he then placed in a pen his brother had made from a wagon wheel spoke. The story, which is highly disputed and is probably myth, at least in part, continues to be included in much of the material written about Waterman and his pen. It should be noted, however, that while many historians deny and scoff at the story, other reliable experts accept it.

Because of his various lines of work, Waterman, it seems, had developed the habit of carrying several fountain pens with him and at times selling some of his extra ones. He had become interested in fountain pens and made a detailed study of pens before becoming a pen manufacturer.



S. R. CROCKETT,
The well-known Novelist, writes:—
"I find that to give away a Waterman's Ideal is to make a friend for life."

SARAH BERNHARDT
writes:—
"The Waterman Pen is admirable—it writes of itself. It is truly the 'Ideal.'"

Waterman's Ideal Fountain Pen

The Ideal Christmas Gift.

"I willingly give my testimony to the supreme excellence of the Waterman's Ideal Fountain Pen. As 'the proof of the pudding lies in the eating,' so I may mention that although I have received at different times various kinds of fountain pens as presents, I have nevertheless been obliged *to invest* in a Waterman's Ideal, and now use it exclusively."
(Signed)
SIDNEY WHITMAN.

POST NOW FOR FRIENDS ABROAD. If you wish to make some friend a gift which will be useful every day through a long period of years, send a Waterman's Ideal Fountain Pen. (Seven of the many varieties only are illustrated.)

Size No. 12. 10/6. Other sizes: Nos. 13, 15/-; 14, 17/6; 15, 21/-; 16, 25/-; 17, 30/-; 18, 35/-.
Size No. 12. 15/-. G.M. Other sizes: Nos. 13, 20/-; 14, 22/6; 15, 26/-; 16, 30/-.
Size No. 22. 15/-. G.M. Other sizes: Nos. 23, 20/-; 24, 22/6; 25, 26/-; 26, 30/-.
Size No. 12. "The Golfer." Silver, 21/-. Other sizes: Nos. 14, 31/6.: 9-ct. Gold, 12, 42/-; 14, 63/-.
Size No. 12. "The Commercial." Silver, 21/-. Other sizes: Nos. 14, 31/6. 9-ct. Gold, 12, 42/-; 14, 63/-.
Size No. 12. Filigree. Silver, 22/6. Other sizes: Nos. 14, 30/-; 15, 36/-; 16, 40/-; 18, 50/-.
Size No. 14. The KING. Silver, 42/-. Other sizes: 9-ct. Gold, 94/6: 18-ct., 189/-.

THREE TRIUMPHS IN FOUNTAIN PEN CONSTRUCTION

Waterman's IDEAL FOUNTAIN PEN.

The popular standard type of Waterman's Ideal, with its perfected spoon feed, is known throughout the civilised world. Over a million were sold last year, and millions are in use. Its main characteristics are its simplicity; its improved and direct spoon feed, which cannot choke and cause the pen to stop writing; its freedom from sudden leakage or blotting. Directly you take the cap from this pen it is ready to write, and does its best work the moment you put the pen to paper. There is not a more perfect fountain pen before the public; and experts agree that it is superior to all its competitors.

Waterman's IDEAL PUMP-FILLING PEN.

Waterman's Ideal Pump-Filling Pen has all the original qualities of the standard type, plus an automatic device for those who prefer a self-filling pen. The majority of writers prefer the simple and direct standard type, but to meet the demand for a self-filling pen, Messrs. Waterman supply the famous Ideal with an ingenious pump which is an improvement on any self-filling device known to the fountain pen world. The pump itself is a neat and strong apparatus which can in no way interfere with the efficiency of the pen. It has no perishable parts, and the pen is simple in construction and holds more ink than any self-filling fountain pen of its size. The pump-filling pen fills itself in a few seconds, and is perfectly clean in use.

Waterman's IDEAL SAFETY PEN.

This, another variation of Waterman's Ideal, has been designed for people who follow an active life out of doors. It is an ideal type for travellers, sportsmen, ladies, and out-of-door workers. The principle is that of a bottle containing ink. Its great advantage is a screw cap which closes flush over the barrel of the pen, into which the nib recedes. It is impossible for this pen to leak, when closed, no matter in what position it is held. Closed, it is as tightly sealed as a bottle with a screw cork. In use it has all the sterling characteristics of Waterman's Ideal, with the same simple and direct flow of ink to the nib and the same equable and easy running qualities.

YOU CANNOT HAVE A BETTER FOUNTAIN PEN THAN THE BEST—WATERMAN'S IDEAL FOUNTAIN PEN. . . .

FOR X-MAS
A Waterman's Ideal Fountain Pen
IN A HANDSOME BOX

Prices:
10/6, 12/6, 15/-, 17/6, 21/- AND UPWARDS
In Silver and Gold for Presentation.
Of Stationers, Jewellers, &c.
Catalogue Post Free from
L. & C. HARDTMUTH, 12, Golden Lane, London, E.C.
NEW YORK: 173, Broadway; PARIS: 6, Rue de Hanovre; VIENNA: Kärnthnerstrasse, 9; MILAN: Via Bossi, 4; DRESDEN: Pragerstrasse, 6; BRUSSELS: 14, Rue du Pont Neuf.

An advertisement for Lewis Waterman's fountain pens, published in the November 21, 1908, issue of The Graphic. (Getty Images)

Life's Work

Whether or not the story of the ruined contract is true, Waterman was working as a life insurance salesman in the early 1880's. It was at this time that he began working on his idea of making a fountain pen with a feed using the principle of capillary action. After several less-than-successful experimental pens, he produced the pen he had envisioned. In 1883, Waterman applied for a patent, which he received on February 12, 1884. Inspired by his success in getting his invention patented, he closed his life insurance business and devoted himself to the making of pens.

He established the L. E. Waterman Company. At first, his company was a one-person operation located in a cigar store on Fulton Street in New York City. His sign advertised Waterman's Ideal Fountain Pen. Each pen carried a written guarantee against defects for five years. Working by himself at a table in the back of the shop, Waterman managed to manufacture two hundred pens the first year and five hundred the second. Waterman's business was small and enabled him to have a personal relationship with each customer. He kept a list of the names and addresses of his customers. However, his profits did not provide enough money to support him.

The Waterman Fountain Pen

Fountain pens were in use as early as the tenth century. However, until Lewis Waterman developed his feed with capillary action based on the principle of capillary attraction, fountain pens were not very practical writing instruments. With an irregular flow of ink, they tended either to skip because of an inadequate amount of ink reaching the nib or to leave puddles of ink on documents because of an excessive quantity of ink reaching the nib. Working alone and using only a pocket knife, a saw, and a file, Waterman succeeded in creating a feed system that regulated the flow of ink and made the fountain pen a practical and enjoyable writing instrument.

His feed system utilized the principle of capillary attraction. As ink left the reservoir, air entered it, avoiding the creation of a vacuum. This was accomplished by letting the ink flow through a channel feed that had fine cuts in it, thus permitting a quantity of air equal to the outflowing quantity of ink to enter the reservoir. Waterman devised a shallow square channel with three fissures. He cut a fissure alongside each wall of the channel and a third fissure in the middle of the channel. This highly successful system, called the three-fissure feed, was the system of ink control used for the next fifty years.

Waterman also designed his pen to provide comfort to the user. His first model had a ridge on the grip. In his second model, he replaced this ridge with a taper, which greatly improved the comfort of the pen's user. Convenience was another important feature of the Waterman pen. It was the first pen to have a clip on the cap.

In addition to making pens that were practical, reliable, and comfortable to use, Waterman made his pens attractive. The first pens were made of hard black rubber. He soon added pens made of hard red rubber and of mottled red and black rubber. He developed and patented a method for machining decorative chasing onto the hard rubber barrels. Many of his pens had elaborate metal overlays. The nibs were gold.

During Waterman's lifetime and until the 1930's, the Waterman pen, synonymous with quality and reliability, was the leader of the fountain pen industry.

Faced with the problem of either increasing his sales or losing his company, Waterman accepted the advice and offer of E. T. Howard, an advertising agent. He proposed that Waterman advertise his pen in a popular magazine with a large circulation. Howard offered to loan him money for the advertisement. Taking Howard's advice proved to be one of the best decisions Waterman ever made. Sales increased dramatically. Waterman was able to move his company to a large building at the corner of Broadway and Courtland Street and to hire a large staff both to handle the business aspects of the company and to manufacture the pens. This building housed the sales and business offices of the company, a warehouse, and a repair shop. Waterman also established two factories: one in Seymour, Connecticut, where the rubber pen parts were made, and one in New York City, where the gold pen nibs were produced. The company sold pens in both the wholesale and retail markets. It also sold ink and pen pockets.

Waterman was an astute and shrewd businessman. His advertising campaign continued to emphasize the quality and reliability of his pens. A Waterman pen was an investment in a quality writing instrument. Waterman was also selective in the people he chose to employ. For example, he hired William I. Ferris to perfect machines for making the pens, thereby reducing hand labor and increasing production.

In 1893, Waterman's Ideal Fountain Pen won a first prize at the Chicago World's Fair. This award was followed by the Medal of Excellence at the Paris Exposition of 1900. The company expanded first throughout the

United States and then abroad. In 1899, the company built a factory in Montreal, Canada. Soon after, the L. E. Waterman Company had sales representatives in Europe. By 1901, the company was selling one thousand pens per day. Lewis Waterman died in New York City on May 1 of that year.

Upon Waterman's death, his nephew Frank D. Waterman became head of the company, which continued to be the leader in the manufacture of fountain pens through the 1920's and enjoyed continued global expansion. It was during this period that the company enjoyed its greatest success and prestige. In the 1930's, competitors who were more open to innovations in style and technical advances took a considerable share of the market from the company. The 1930's and 1940's saw the L. E. Waterman Company lose even more ground in the pen market. The invention of the ballpoint pen was the major cause of the demise of the business, which ceased production in 1956. The L. E. Waterman Company was eventually sold to Bic in 1959. However, in 1926 Jules Fagard, a French sales representative, had founded a subsidiary known as JiF Waterman, so pens bearing the name Waterman continued to be produced. Waterman pens continue to be available.

IMPACT

Waterman developed the capillary feed system, which successfully controlled the ink flow to the nib of the fountain pen. Before Waterman's invention, fountain pens had been considered impractical because of their unreliability and tendency to either release too much or not enough ink. His invention of this feed system and manufacture of pens using the system founded a new industry in the United States and eventually worldwide. In addition to producing a reliable pen, he also produced an attractive pen. Fountain pens became a status symbol for individuals and a profitable business for entrepreneurs.

—*Shawncey Webb*

FURTHER READING

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Rosenberg, Chaim. *America at the Fair: Chicago's 1893 World's Columbian Exposition*. Charleston, S.C.: Arcadia, 2008. Chapter 6 examines the business climate in which Waterman worked and the competition that occurred among the manufacturers. Waterman's Ideal Fountain Pen won first prize at the fair.

See also: William Seward Burroughs; Bette Nesmith Graham.

SIR ROBERT ALEXANDER WATSON-WATT

Scottish physicist

Watson-Watt is often described as the "father of radar." His experiments and research established the foundational physics of radar, while his administrative efforts and persuasiveness were instrumental in the development of a radar-based air defense system. While Watson-Watt's work focused on the military applications of radar, the wartime development of miniaturized radar made possible the radar-based technologies in navigation, traffic control, meteorological prediction, and tracking that so pervade the modern world.

Born: April 13, 1892; Brechin, Forfarshire (now Angus), Scotland
Died: December 5, 1973; Inverness, Inverness-shire, Scotland
Primary fields: Military technology and weaponry; physics
Primary invention: Radar-based air defense system

EARLY LIFE

Robert Alexander Watson-Watt was born in Brechin, Scotland, to Patrick and Mary Watt. Robert was raised in a practical family whose head, Patrick, worked as a carpenter and a joiner. Robert was a successful student at the University of St. Andrews in Dundee, Scotland. While Robert enrolled in the pragmatic field of engineering, his principal interest was in physics, a field in which he excelled. When he graduated in 1912, his placement in the top of his class garnered for him a position as a teaching assistant in the physics faculty. He remained in academia until Great Britain began to mobilize its intellectual resources during World War I.

In 1915, Watt's physics skills secured him employment in the Meteorological Office. This was the first in a series of government service positions he would hold until 1952. World War I saw the evolution of airplanes from fragile curiosities to important weapons of war whose use significantly affected battles. This was partially the result of technological innovations such as bigger engines and structurally improved airframes, but equally consequential was the creation of the infrastructure needed to supply and support aerial operations. This infrastructure was essential in the formation of the Royal Air Force (RAF). This included not only pilots, mechanics, and armorers but also specialists such as meteorologists who could track and predict weather, since storms often interfered with or delayed operations. Watt's experiments focused on using radio waves to detect storms, for early on he discovered that the electrical discharges in storms interfered with radio transmissions. At about the same time, scientists in the United States noted that this interference showed up as a visible pattern of disturbance on a cathode-ray-tube display, and Watt understood that these disturbances offered a visible and quantifiable way to identify and track storms.

In the postwar years, Watt continued to work as a researcher in the Air Ministry. By the 1930's, his work was well respected within the scientific community, so when scientists in the ministry began to investigate the implications of research on radio waves, Watt was an obvious person to consult.

Life's Work

One aspect of aerial combat in World War I that resonated with Britain's population was what would later be termed "strategic bombardment"—the use of bombers to attack and destroy an enemy's war industries. While both sides launched air raids on cities, the best-known attacks were those made by German dirigibles against London. Although these attacks caused little actual damage and insignificant casualties, they had a huge impact on the British public, who saw the RAF's inability to stop raids as an admission of British vulnerability. Consequently, the interwar years saw Britain invest great effort into developing defenses against aerial attacks. While much of this effort built upon scientific engineering such as the development of fast all-metal monoplane fighters, no scheme seemed too absurd if it seemed to offer safety from aerial attack. Thus, even ideas that sounded like science fiction were investigated. A few of the more esoteric proposals that were seriously investigated were death rays and aerial mines attached to parachutes that would be dropped in front of attacking bombers.

A Radar-Based Air Defense System

An air defense system must overcome the following problems: monitoring the incoming bombers, identifying their target(s), massing the defending fighters before the target at altitudes that maximize their effectiveness against the bombers, and inflicting enough casualties among the bombers to force them to either abort the attack or to bomb ineffectively. Prior to pre-World War II British efforts, air warning was based on sound detection or visual identification—both of which suffered from the technological limits of short range. Likewise, air defense was based on manually aimed antiaircraft guns and fighters circling over likely targets in perpetual air patrols. The first method was inaccurate, and the latter degraded the fighter pilots' effectiveness as they burned fuel and exhausted themselves in long patrols.

The air defense system based on Robert Alexander Watson-Watt's Chain Home (CH) radar system (a network of radar stations that initially dotted the south and east coasts of England) and the Biggin Hill experiments was a multifaceted system whose effect was a synergetic combination of technologies. The CH towers were set in a grid so that long-range echoes of incoming aircraft could be identified from numerous towers and triangulation could establish their routes and probable targets. This information would then be telephoned to a plotting room where the data could be processed and appropriate fighter squadrons alerted. The fighters, once airborne, could then be vectored by radio to the correct target and altitude—or be easily rerouted. The fresh fighters with full tanks of gas could then ambush the bombers and their fighter escorts near the end of their range after long over-water flights. This gave the defending fighters a great advantage in almost every encounter. As a result, the ratio of losses during the Battle of Britain (1940) ran against the Germans. The failure of the Luftwaffe to subdue the Royal Air Force was Nazi Germany's first major defeat of the war.

It was the improbable quest for a death ray that propelled Watt into his role in the creation of radar. In 1934, an Air Ministry committee tasked with the development of new technologies for air defense approached Watt and asked him to evaluate a proposal for the creation of a death ray to be used against aircrew. Watt then instructed his subordinate, Arnold "Skip" Wilkins, to calculate the power needed to raise eight pints of water from 98° Fahrenheit to 105° Fahrenheit, a fatal body temperature. Wilkins's figures demonstrated that the power demands of such a weapon made it impractical.

In February, 1935, Watt reported these findings in a memo, *Detection and Location of Aircraft by Radio Methods*. Watt claimed that while a death ray was not viable, a detection system based on radio echoes was feasible, if funding for research was provided. Watt's memo was one of the first items addressed by the newly created Committee for the Scientific Survey of Air Defense, unofficially called the Tizard Committee after the name of its chair, Henry Tizard. The Tizard Committee was to be a coordinator of scientific research, a facilitator of government funding, and a "cheerleader" with government leaders such as Winston Churchill. Through the Tizard Committee's support, a group of scientists, including Watt, were gathered to study what they called radio direction finding (RDF) and to create the machinery that would turn RDF from concept into what is now commonly called radar (an American acronym for "radio detection and ranging").

Detecting incoming aircraft was only half the battle. To make radar useful, a system had to be created to link radar with defending fighters. Air Marshal Hugh Dowding was a member of the Tizard Committee; in 1937, he authorized a series of field tests known as the Biggin Hill experiments. Biggin Hill was an RAF fighter base, and the experiments addressed how to couple radar detection of incoming aircraft with fighter planes. These experiments worked out how to use a centralized plotting team to analyze radar data to predict the target of incoming bombers and then communicate this data to airfields near the target in time to allow effective response. Forewarned defending fighters could rapidly scramble and be vectored directly to the oncoming bombers. This system appears complex, but offered the advantage of allowing defending fighters to be ready, rested, and fully fueled until the last moment—which was a very real advantage since the bombers would be fighting near the end of their radius of action. This system was unprecedented for its sophistication and unmatched by any other nation. Historians of World War II's aerial campaigns ascribe Britain's victory in the Battle of Britain to this radar-based system.

During and after the war, Watt portrayed himself as the innovator and leader of this effort, claiming, "I modestly believe myself to be the father of radar." Watt was central to this effort in part because he recruited a number of the talented scientists involved in the research. In addition, Watt was assigned increasingly important roles as the administrator of crucial research bodies such as the Radio Research Station; eventually, he became the director of communications development, a generically named position that disguised the military nature of his work.

While Watt styled himself as the "father of radar," there were many fathers. The Tizard Committee, for example, brought together scientists, engineers, and administrators such as Watt, Tizard himself, Wilkins, Edward "Taffy" Bowen, and Dowding. Each man's efforts contributed to the creation of Britain's multifaceted and effective air defense system. Parliament's funding resulted in the creation of a series of radar stations along the coast known as the Chain Home (CH) system.

While the CH system allowed Britain to be the first nation to deploy an effective and coordinated radar-based air defense system, other nations' scientists had also been aware of the use of radio waves to detect aircraft and had been working on their own versions of radar. What gave legitimacy to Watt's claims to be the "father of radar" was that he was one of the first to take out patents—albeit secret patents—on radar technology, and he ultimately headed a number of organizations that researched and developed the radar hardware used by Britain during the war. It was under Watt's direction, for example, that Taffy Bowen worked to create radar that would fit an airplane. While Watt's ideas and persuasiveness continued to drive radar research, some of the difficulties faced by the British were the unintended results of Watt's initial work. Watt's early storm-tracking apparatus worked best when the radar operated on the long wavelength of approximately 1.5 meters. Long wavelengths required huge receivers, and the CH stations stood over 200 feet high. Such large receivers could not be made mobile or be mounted in aircraft, so much of Bowen's efforts at creating an airborne radar set were focused on the creation of a radar set that would operate at centimetric wavelengths.

Both the Tizard Committee and the government recognized the importance of Watt's ideas and leadership, and in 1942 Watt was knighted. In response to his new station, Watt hyphenated his last two names and became Watson-Watt. With his promotion to the post of director of communications development, Watson-Watt controlled radar research throughout the war. It was in this position that he also was responsible for sharing British radar research with the Americans so that their research could be accelerated and their productive capacity could meet Britain's increasing demand for radar sets.

IMPACT

Watson-Watt's initial observations and ideas had been significantly enhanced by the work of a number of scientists, many of whom he had recruited. His enthusiasm and drive made him a booster of the technologies, while his self-serving efforts resulted in his holding a number of leadership positions in the British radar program. From these positions, he coordinated others' ideas, which resulted in such advancements as airborne mounted radar, radar navigation, and the sharing of radar technologies with the Americans. These advances, when tied to the initial radar-based air defense system, proved to be pivotal parts of the successful Allied aerial campaigns in World War II. Following the war, radar technologies were used in navigation, identification of airplanes for air traffic control, and eventually meteorological studies. In these capacities, radar has reshaped the world.

—*Kevin B. Reid*

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See also: Luis W. Álvarez; Edwin H. Armstrong; Karl Ferdinand Braun; John Presper Eckert; Reginald Aubrey Fessenden; Peter Carl Goldmark; Heinrich Hertz; Erna Schneider Hoover; Karl G. Jansky.

JAMES WATT

Scottish mechanical engineer

Watt's improvements to existing steam engines, including the introduction of a separate condenser that allowed a faster rate of operation and a significant saving in fuel, revolutionized the mining and textile industries in England and the world in the late eighteenth and into the nineteenth century.

Born: January 19, 1736; Greenock, Renfrewshire, Scotland
Died: August 25, 1819; Heathfield Hall, Warwick, England
Primary fields: Manufacturing; mechanical engineering
Primary invention: Improved steam engine

EARLY LIFE

James Watt was born in a small Scottish fishing village, Greenock, on the Firth of Clyde on January 19, 1736, the fourth of five children. His paternal grandfather, Thomas Watt, was an instructor in navigational mathematics, and his father, James, was a carpenter, surveyor, merchant, shipbuilder, and town official. James senior married Agnes Muirhead, a woman from an old, distinguished family, with relatives at the University of Glasgow. The young James showed an interest in mathematics at an early age, but because of ill health, he was educated by his parents at home. He spent his spare time at his father's workbench, constructing models of various mechanisms in wood and metal. At the age of thirteen, James was sent to the village school, but at this time he did not show any propensity for genius.

When James was eighteen years old, he went to Glasgow to learn the trade of a mathematical instrument maker, but there was not a competent master craftsman in that town with whom he could pursue an apprenticeship. In 1755, he was advised to move to London, the seat of scientific instrument making, where he would find the proper instruction. He worked for a year with John Morgan, who charged James twenty guineas to teach him the trade, and returned to Glasgow intent on pursuing his new craft. Unfortunately, since he did not serve his apprenticeship in Glasgow, the trade guilds would not allow him to open a shop in the town. He was then employed by Dr. Robert Dick of the University of Glasgow to clean and repair several scientific instruments brought to the university from the West Indies.

The Improved Steam Engine

James Watt realized that to reduce the consumption of fuel, the cylinder of a steam engine must be maintained at a high temperature, but to achieve maximum power, the cylinder must be cooled down to produce a vacuum. The inventor, during a contemplative Sunday walk, hit upon the idea of a separate vessel, a condenser that would remain cool and into which the hot steam would be introduced. The cylinder with the piston would remain hot, a vacuum would be produced in the condenser with a pump to expel air, steam would rush in and condense, and the piston in the still-hot cylinder would be forced up. Watt constructed an experimental apparatus with a steam jacket around the cylinder that gave such good results that he decided to produce a full-size engine.

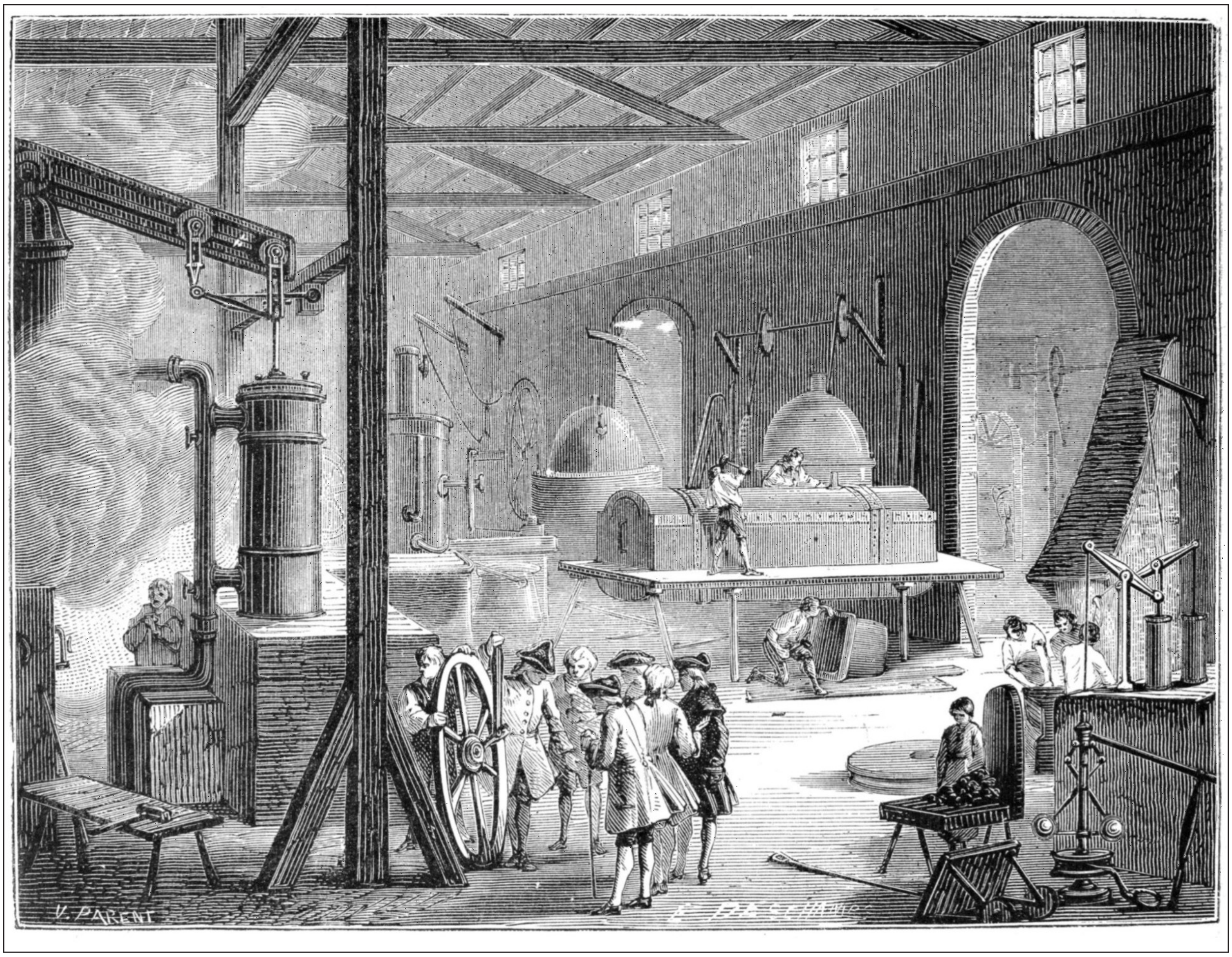
The first commercial-grade Watt steam engine with a fifty-inch cylinder was completed in 1776 and successfully put into service at the Bloomfield Colliery in Staffordshire, England. The engine consumed only about 25 percent of the fuel of a typical Newcomen engine and provided three times the power. The Matthew Boulton and Watt partnership charged a royalty to mine owners using their engines based upon one-third of the savings in fuel compared to the Newcomen engines then in service. Within a few years, improvements to the basic engine included a larger boiler, a more efficient plug rod connected to the horizontal beam to open and close the three main valves of the system, a more efficient stuffing box through which the piston rod passed, more insulation provided to the top of the cylinder, an improved internal water jet head to condense the steam and to create a vacuum below the piston, and a piston ring of tallow-soaked hemp to reduce leakage between the piston and the cylinder wall.

The partnership did not provide a ready-to-run engine to its coal mine customers. Rather, the client provided most of the material at his cost to build the engine, with the exception of the valves, and Boulton and Watt supplied the drawings and a construction supervisor to oversee the project. This arrangement was modified somewhat for textile mill operators. The firm of Boulton and Watt prospered over the next quarter century, earning wide recognition as one of the premier business concerns in Europe.

Life's Work

As early as the seventeenth century, experimenters were working with steam apparatuses to achieve various purposes with varied results. In 1679, a French physician, Denis Papin, invented the pressure cooker, a steam-powered cooking implement that utilized the heat of steam under pressure to speed up the cooking of meat and vegetables. With modifications including the addition of a piston, Papin produced a rudimentary steam engine. Thomas Savery, an Englishman, developed a "fire engine" (1698) for raising water from mines. He was hampered, however, by the limits of the technology of that time, which did not allow the creation of a permanent vacuum that would produce the high boiler pressures necessary to raise water to a practical level in flooded coal mines. By 1718, John Theophilus Desaguliers had improved upon the Savery engine by designing a jet-spray head that introduced cooling water directly into the cylinder of this apparatus to initiate a vacuum more rapidly than had been possible before. In 1712, Thomas Newcomen, another Englishman, improved the Savery engine by designing a piston in an enclosed cylinder and a separate boiler that, along with other innovations, made this the most successful steam engine for raising water from mines up to that time.

In 1763, Dr. John Anderson, professor of natural philosophy at Glasgow, assigned Watt the task of repairing a model of a Newcomen engine belonging to the university. By 1764, Watt had the machine in working order, but he was shocked at the amount of steam loss and fuel consumption due to the heating and then cooling of the cylinder. Watt had studied chemistry, was familiar with the work of Savery, Newcomen, and Desaguliers, and used this knowledge to continue experimenting and improving his engine. Soon, Dr. Joseph Black introduced Watt to John



Soho Manufactory in Birmingham, England, where James Watt and his partner, Matthew Boulton, manufactured steam engines from 1775 to 1800. (The Granger Collection, NewYork)

Roebuck from Birmingham, the owner of the Carron Iron Foundry in Scotland.

In 1767, Roebuck agreed to assume Watt's debts in return for a two-thirds interest in the improved steam engine. The work on a new model proved so encouraging that Watt went to London in 1768 and successfully applied for a patent, which was granted the following year. In 1768, Watt returned to Scotland and built a large engine at Roebuck's house at Kimmeil with a cylinder of eighteen inches in diameter and a stroke of five feet. This engine showed promise, but the poorly bored cylinder leaked profusely, and Watt was not able to find a material that would provide a steam-tight seal around the piston. As a result, work on this engine stopped as Roebuck's financial situation steadily deteriorated.

Fortunately, while he was returning from London after submitting the patent application, Watt stopped in Birmingham and met the wealthy industrialist Matthew Boulton, the owner of the famous Soho Manufactory. Later, Boulton agreed to assume Roebuck's debts in return for the two-thirds share of Watt's invention, and in 1774 Watt relocated with his engine and his two young children to Soho. His wife, Margaret Miller, had died of a sudden illness several months before. The problem of the imperfect cylinder was solved when John Wilkinson of Bersham manufactured an improved boring machine and produced for Watt a nearly perfect product that did not allow steam to escape around the piston.

Boulton realized that the fifteen-year 1769 patent would expire before a profit could be realized, so he insisted that Watt apply for a patent extension. The extension was granted for a period of twenty-five years in

1775, giving the new partnership of Boulton and Watt a virtual monopoly on steam engines until the year 1800. The partners vigorously contested patent encroachments for the next twenty-five years.

Other inventions ancillary to the steam engine followed in rapid succession between 1775 and 1785: the sun-and-planet gear wheels that allowed for rotary motion in Watt's steam engines, the utilization of the expansive properties of steam, the double-acting steam engine, a counter that recorded the number of strokes that an engine made, the fly-ball governor, and the glass water gauge.

By 1800, both Boulton and Watt were aged, and somewhat feeble, but had grown quite wealthy from the royalties realized from their patents. By this time, the partners were ready to turn their business over to their two sons who had been groomed for years to assume the responsibilities of the enterprise. Boulton continued to participate in business ventures until his death at the age of eighty on August 17, 1809; Watt retired to his attic workshop at his home at Heathfield and for the remaining years of his life amused himself in tinkering with gadgets and being cared for by his second wife, Ann McGregor, a meticulous housekeeper who reputedly trained her two dogs to wipe their paws on a doormat before they entered the house.

As a result of his accomplishments, Watt was afforded numerous honors in his later years. He was elected a fellow of the Royal Society of Edinburgh in 1784 and a fellow of the Royal Society of London in 1785. In 1806, the University of Glasgow awarded him an honorary LL.D., and in 1814 the Académie des Sciences in Paris elected him as one of its only eight foreign associates.

Watt was sickly for most of his working life. However, when he retired, his health slowly improved, and he enjoyed good health until one month before his death at Heathfield, on August 25, 1819. A marble statue of Watt was erected in 1824 in Westminster Abbey, a fitting tribute from the people of England who owed him so much.

IMPACT

Watt did not invent the steam engine. The previous inventions of Savery and Newcomen were not efficient because of the large amount of fuel they consumed, but they laid the foundation for the improvements that Watt initiated after years of experimentation. With Watt's idea that a separate condenser would save fuel costs, the stage was set for the production by his partnership of more than five hundred steam engines that revolutionized the conversion of heat energy to mechanical power. Watt's steam engine became the major power source around the world during the nineteenth century. It was used in manufacturing and transportation, both on land and on the ocean. The success of the British textile industry was due, in large part, to the dependable power provided by the rotary motion of steam engines. For the first time in history, mills could be located away from the undependable water-power sources of rivers and streams.

The theory behind steam power was not fully understood in the early days of the construction of the first steam engines. Only over the course of many years of trial and error were the most economical fuel and pressure settings discovered by the members of that newest profession, the engineers. Steam engines were replaced after two hundred years of service in factories by electric motors, but since electricity is still produced by steam turbines and generators, it is fair to say that steam power is still very much a part of the modern world.

—*Charles A. Dranguet, Jr.*

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See also: Sir Richard Arkwright; Giovanni Branca; Sir Humphry Davy; Robert Fulton; Thomas Jefferson; Charles Macintosh; William Murdock; Thomas Newcomen; Nikolaus August Otto; Joseph Priestley; Thomas Savery; Richard Trevithick.

GEORGE WESTINGHOUSE

American engineer

Westinghouse's invention of dependable braking systems for trains, controlled from the locomotive by the engineer or from railcars by conductors, brought him recognition and enormous wealth. Westinghouse received patents for 361 inventions during his career, and by the beginning of the twentieth century he had organized more than fifty companies, thirty of which he served as president.

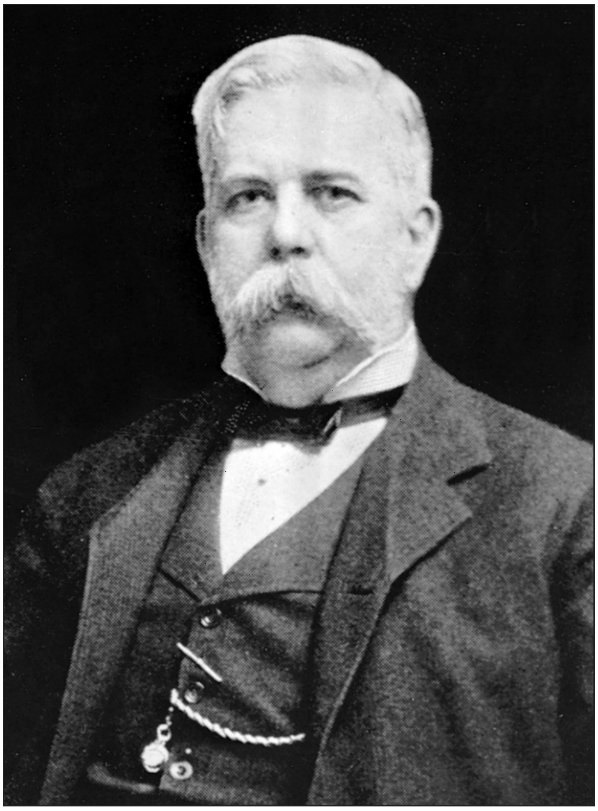
Born: October 6, 1846; Central Bridge, New York
Died: March 12, 1914; New York, New York
Primary fields: Manufacturing; railway engineering
Primary inventions: Railway air brakes; railway signaling system

EARLY LIFE

George Westinghouse was a restless child, hard to control and given to tantrums. He was an inattentive student whom his teachers considered lazy and virtually unteachable, although he demonstrated ability in mathematics and freehand art. The seventh of ten children born to George and Emmeline Vedder Westinghouse and the second youngest of the eight who survived, George was reserved and solitary, living in his own world, the often misunderstood world of the active imagination.

George, Sr., was a resourceful farmer who taught himself carpentry and understood how things worked mechanically. He ran a farm machinery repair shop where he manufactured machines to increase the efficiency of planting and of harvesting crops. He held patents for seven of the implements he invented. In 1856, the Westinghouse family moved to Schenectady, New York, where George, Sr., expanded his repair shop under a new name: George Westinghouse and Company. His shop prospered, and the family became comfortable financially. During the summer of 1859, George, Jr., working in his father's shop, developed a rotary engine for which he obtained a patent at age fifteen. George, Sr., assigned his son many menial tasks, such as sweeping the shop's floor.

One day, when the men working in the shop were permitted to go home, George, Sr., assigned his son the seemingly meaningless task of cutting a huge pile of metal pipes into equal lengths. George, Jr., who probably wanted to end his day and go home as the other workers had, knew better than to complain. He did the next best thing: He used his mechanical skill and imagination to complete the task expertly. Although it would have taken several days to finish this job had George taken each length of pipe, measured it, and cut it to specification, he invented a method using a steam-powered lathe to do the



George Westinghouse. (NARA)

job in a couple of hours and with such precision that each length of pipe was virtually identical to the others.

When the Civil War began in 1861, Westinghouse, lying about his age, joined the Union Army, but when his deception was uncovered, he was sent home. In 1863, now old enough to serve, he enlisted in the Army. After a year, Westinghouse, at his own request, was reassigned to the Navy as an assistant engineer on two ships assigned to enforce the blockade of southern seaports. Returning from the war, Westinghouse enrolled in Schenectady's Union College, acceding reluctantly to his father's wish that he continue his formal education. Totally bored by the experience, he dropped out after three months and embarked on his life as an inventor.

LIFE'S WORK

In 1867, back in Schenectady, Westinghouse married Marguerite Walker, with whom he had one child. Pursuing his interest in rail transportation, he invented a device that could set derailed trains back on the track. He also invented a railway switch that was more durable than previous switches. By 1868, Westinghouse had moved to Pittsburgh after abortive attempts to market these new devices. By the following year, however, he had invented an air brake system for railways that was vastly superior to the unwieldy braking systems then in general use. Westinghouse was granted a patent for the air brake on April 13, 1869.

A savvy businessman, Westinghouse subsequently established the Westinghouse Air Brake Company. Although he continued to produce air brakes and to work on a variety of other inventions, his monumental fortunes were not assured until 1893, when the United States Congress passed the Railway Safety Appliance Act mandating the use of air brakes on all railway cars in the United States.

Having created means by which American railroads could operate more safely and faster, Westinghouse now turned his efforts to perfecting remotely controlled railroad signaling and switching devices. He acquired patents that he combined with his own inventions to improve devices in these areas. In 1881, he established the Union Signal and Switch Company to manufacture signaling and switching devices and to accommodate railroads hungry for such advanced and sophisticated implements.

Early in the 1880's, Westinghouse found that his electrical signaling and switching devices worked better on alternating current (AC) than on direct current (DC). Direct current could be used only within a radius of two or three miles, whereas alternating current could be transmitted over considerable distances. Westinghouse's claim ran counter to that of Thomas Alva Edison, who considered alternating current dangerous.

RAILWAY AIR BRAKES

Central to George Westinghouse's prominence as both inventor and businessman was his invention of greatly improved air brakes that eventually, through an act of Congress, were required on all railway cars in the United States. Previous braking systems required that brakemen engage a train's brakes individually for each railway car. Westinghouse's invention enabled the locomotive engineer or the conductor to engage all of the brakes simultaneously and bring their trains to a halt.

Whereas many early trains consisted of few cars and operated over relatively flat surfaces, later trains could consist of dozens of cars and often were operated in mountainous areas, making it essential that they could be stopped quickly to prevent collisions and possible derailments. Initially a straight air system was employed. In this system, compressed air is released to push on a piston housed in a cylinder. Through its connection with pistons on other railway cars, pressure is exerted on each car's brakes, creating the friction needed to reduce the train's speed dramatically and quickly. The mechanical connection thus achieved distributes the force from one cylinder to many wheels. The pressurized air required for such an operation is supplied by an air compressor housed in the locomotive and controlled by the engineer. It is sent from its source to all of the train's cars through pipes installed beneath each carriage and connected to other railway cars through hoses that join them. The only significant problem with such a system is that if the hose connecting the cars become disconnected, the pressure needed to apply friction to the brakes can be lost, resulting in derailment or collision.

Westinghouse addressed this problem by inventing a control valve for railway cars. It consisted of three parts: a diaphragm-operated feeding reservoir to feed compressed air to the brake cylinder, the reservoir charging valve that assures equalization of pressure, and the brake cylinder release valve that is engaged when a train's speed has to be reduced or when the train has to be brought to an immediate stop. This system uses a decrease in air pressure on the train line to engage the brakes. The engineer can thereby control from the locomotive the braking system for an entire train, which makes it unnecessary for railways to hire a cadre of brakemen to engage individual braking systems for each railway car.

Westinghouse, however, developed a meter that greatly reduced the danger from alternating current. He also invented a similar meter that took much of the danger out of the transmission of highly explosive natural gas. Despite this, much of the public sided with Edison, who was regarded as the elder statesman in matters involving electricity.

When the state of New York reached the decision to punish those condemned to death for committing capital crimes by electrocuting them, it mandated that the state's electric chair should operate on alternating current, which was used in 1890 when William Kemmler became the first person to be executed in this manner. Nevertheless, in time it became evident that alternating current was more practical, in most situations, than direct current.

As early as 1882, when Westinghouse learned that Lucien Gaulard and John D. Gibbs had developed AC generators and transformers to regulate the voltage of alternating current, he bought their patents and studied their implements extensively. In 1884, he established the Westinghouse Electric Company, a corporation that manufactured a variety of electrical devices powered by alternating current. It took seven years for Westinghouse to perfect an induction meter that would enable alternating current to be used domestically and safely.

Westinghouse was a visionary who realized the potential of electrical power. Earlier than most of the scientists and inventors of his day, he knew that the limitations of direct current would severely impede its practical application. Realizing that alternating current posed safety problems, he set about finding a means to control these problems.

Westinghouse employed Nikola Tesla and other eminent scientists and inventors to help him build safe AC motors so that high-tension current could be transmitted in a carefully controlled and safe manner. With a virtual stable of such high-powered inventors, he set about harnessing the hydroelectric power of Niagra Falls, which produced enough power for the whole of Buffalo, New York.

The Westinghouse Electric Company's chief competitor was the General Electric Company. Westinghouse was clearly the more inventive company. In 1896, General Electric reached an agreement to use many of Westinghouse's patents. By the dawn of the twentieth century, the Westinghouse Electric Company was among the preeminent corporations in the United States, with a workforce exceeding fifty thousand. The company continued to prosper until 1907, when a nationwide financial panic threatened the U.S. economy, forcing Westinghouse Electric into bankruptcy, from which it emerged the following year. George Westinghouse was deeply shaken by this event. In 1911, now sixty-six years old, he ended his direct association with the company.

During his last three years, Westinghouse devoted himself to public service endeavors. The directors of the bankrupt Equitable Life Assurance Society enlisted Westinghouse's help to save their company. Working feverishly to bring this corporation back from bankruptcy, Westinghouse, by the time he died, had transformed it into the vibrant company it had been before its collapse.

IMPACT

Westinghouse is at the forefront of legions of inventors and scientists who transformed American society in the last half of the nineteenth century from agriculture to industry. It would be difficult for anyone living in the twenty-first century to go through a day without being in some way affected directly by several of the innovations Westinghouse brought to the public.

Although the automotive industry was in its infancy, Westinghouse experimented with air springs to use in automobiles and received patents for such devices. He continued to experiment with steam turbines as generators of electrical power.

Without the advances he made with electricity, the space age would have been impossible. On a practical level, rail transportation of both freight and passengers was greatly enhanced by Westinghouse's invention of air brakes and of signaling devices.

Ever mindful of safety, Westinghouse assessed problems relating to the distribution of electricity and natural gas and set out to overcome these problems. The meters he developed to control the flow of such energy resulted in the safe distribution of these energy resources domestically and industrially.

Westinghouse's impact upon American society was broadly recognized and honored. Although he is said to have spent only a year and a half in school after age thirteen, he was the recipient of many honorary doctoral degrees, including one from Union College, where, during 1866, he had spent three months as a student before dropping out.

—*R. Baird Shuman*

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See also: Edward Goodrich Acheson; Thomas Alva Edison; Reginald Aubrey Fessenden; Charles Martin Hall; Peter Cooper Hewitt; Elijah McCoy; Nikola Tesla.

DON WETZEL

American computer programmer

Wetzel conceptualized and helped design the first successful automated teller machine (ATM). Though other ATMs had been developed before the Wetzel ATM, he developed the management ideas that made the invention a success, showing banks how to generate a population of clients who used the machines.

Born: 1928; New Orleans, Louisiana
Also known as: Donald Claude Wetzel (full name)
Primary field: Mechanical engineering
Primary invention: Automated teller machine (ATM)

EARLY LIFE

Donald Claude Wetzel was born and reared in New Orleans, Louisiana. He attended Jesuit High School and was the star shortstop on the baseball team. He played professional baseball in the New York Giants farm system for three years while attending the University of Loyola in New Orleans. He graduated in 1951 with a bachelor's degree in foreign trade and was offered a job at Service Bureau Corporation, a subsidiary of International Business Machines (IBM). Realizing that he would not make the major leagues, he accepted the position. The company processed data such as payroll, accounts receivable, and sale analyses for companies that did not have IBM machines. Wetzel worked five years in New Orleans before moving to Fort Worth, Texas, to become a branch manager. After several years, he became a systems engineer in San Antonio. Before computers, he was the person to wire the panels, write the procedures, and train the personnel. After computers became available, he started programming. In 1958, he moved to sales, and in 1960 he became a "special representative" for IBM. His duties centered on assisting salesmen in securing orders with banks. In 1963, he moved to Houston as a sales manager responsible for five industries: financial, insurance, communication, utilities, and transportation (FICUT). In 1968, IBM wanted Wetzel to move to New York, but he instead accepted a job as vice president of product planning with the Docutel Corporation in Dallas, the company that developed automated baggage-handling equipment.

LIFE'S WORK

While standing in line at a bank, Wetzel realized that a machine could do almost all the tasks of a teller. Mentioning this at one of the weekly company meetings, Wetzel received enough encouragement to generate a feasibility study. The company had to know how many machines could be sold and how many people would use them. Docutel convinced a University of Dallas graduate program to do a study as well. The studies found that people preferred speed and convenience to personal, face-to-face service. With these positive studies, a proposition was made to the board of directors of Recognition Equipment, Docutel's parent company. The board agreed to invest $4 million in the development of an automated teller machine (ATM).

To be a stand-alone (offline) machine—that is, having no communication with the bank's computer system—the ATM needed some information about the client before it could dispense money. A data card similar to a credit card was used by the client to provide information to the machine. In addition to the card reader, the machine needed two others parts: a cash dispenser and a printer to make a record of the transaction for the bank and a copy for the customer. Similar devices had already been developed, but Wetzel and the development team had to produce or significantly modify each device for the teller machine.

The first ATM was installed at New York's Chemical Bank, which had loaned money to Docutel. The bank advertised that it would open on that morning in September, 1969, "and never close again": Since there was an ATM open twenty-four hours a day, seven days a week, it would be as if the bank were always open. Though the first machine was only a cash dispenser (the full-service teller machine was a few years in the future), it was a success. Banks began to buy and advertise ATMs, and qualified bank customers received ATM cards. At one time, Docutel had so many orders that it did not have enough money to buy all the supplies needed to build the machines.

In 1973, a patent for the machine was issued to Wetzel, Tom Barnes, the mechanical engineer, and George Chastain, the electrical engineer. They had started plans for a full-service teller machine when Wetzel resigned from the company to be able to spend more time with his family. His first wife, Gladys, died of cancer in 1970. In 1972, he married Eleanor, a widow with eight children. With his four children and her eight all at home, Wetzel decided that his job at Docutel required too much travel. That year, he started his first business, Financial Systems and Equipment. He became a manufacturer's representative for all kinds of bank equipment except computerized equipment. The company was a success. In 1978, Wetzel and another former Docutel employee started Electronic Banking Systems (EBS), a consulting business for banks in the ATM business. According to Wetzel, EBS was the first company to place ATMs in supermarkets. The ATMs by this time were full-service machines connected to the bank's computer. EBS would buy an ATM and program it to charge a small fee for each transaction, and EBS and the supermarket would split the money. The company was so successful that it was bought out by Docutel in 1984. Part of the terms of the sale was that Wetzel and his partner would work for Docutel for a period of time.

In 1979, Wetzel started a third company, Autosig Systems, which sold electronic signature verification systems. Wetzel retired in 1989, although he remained on

The Automated Teller Machine

The ATM was developed by Don Wetzel and the Docutel Corporation and was first installed at a bank in 1969. The ATM had three main components: the card reader, the cash dispenser, and the printer. The card reader read the bank-issued card that contained the customer's data, including checking, savings, and credit card account numbers, the bank's routing and transit number, and the number of times per day that the card could be used. All this data was placed on a magnetic strip on the data card. It was encrypted so that no one could read the magnetic strip without the encryption codes. A client could withdraw a certain amount of money with each transaction and only so many times per day. Wetzel and his team had to build a module to be placed inside the machine that would rewrite the magnetic code each time the card was used. Then they had to design a module to produce the cards for the banks to replace lost cards.

Designing the cash dispenser was a greater issue. The dispenser had to give out the right amount of money, so it had to dispense one bill at a time. Also, engineers had to ensure that the dispenser would not jam, else the machine would record a transaction though the customer would not get money. It was determined that the cash had to be new or almost new, fairly crisp bills for the dispenser to work correctly and continuously.

The printer had to print a record of the transaction, including the account number, amount of money withdrawn, date, time, and the bank's routing and transit number, as well as make a copy for the customer. The bank's copy had to be written so that the bank's mainframe computer could read the transaction. Numbers printed on paper with normal ink were not readable by a computer, so the transaction record had to be written in magnetic ink character recognition (MICR) format. The MICR format was developed for the processing of checks. Besides having a certain font, the characters were printed with an ink that contained magnetic particles, usually iron oxide. The printer could not only print the transaction record correctly every time for both bank and customer but also print the bank copy in the MICR format. This feature made the printer more sophisticated than was originally anticipated.

All the parts were fit into a mechanical box whose stainless steel frame was ⅝ inch thick. This frame provided sufficient security: It would have taken several hours for a thief using a blowtorch to cut into the box to steal the money. In addition, heat sensors were installed on the machine to melt any ice that formed there.

the board of Autosig Systems. In 2003, Jesuit High School recognized him as alumnus of the year.

IMPACT

Wetzel helped change the way people bank. Wetzel and Docutel's studies indicated that bank customers preferred speed and convenience over face-to-face service, and Wetzel met this demand with the automated teller machine. Instead of entering the bank, customers can go to an outside ATM and deposit or withdraw money, pay the mortgage, or transfer money from one account to another at any time, twenty-four hours a day, any day of the week. Between 1995 and 2008, the number of ATMs in the United States grew from 187,000 to 406,000.

—*C. Alton Hassell*

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See also: William Seward Burroughs; Herman Hollerith; Dean Kamen; Jerome H. Lemelson.

CHARLES WHEATSTONE

English physicist

Wheatstone was a prolific inventor in the fields of acoustic and electric technology. He is best known for his invention of new musical instruments and his contributions to the development of telegraphy.

Born: February 6, 1802; Barnwood, Gloucestershire, England
Died: October 19, 1875; Paris, France
Also known as: Sir Charles Wheatstone
Primary fields: Communications; music; physics
Primary inventions: Enchanted lyre; electric telegraph

EARLY LIFE

Charles Wheatstone was the second of four children and the younger son of William Wheatstone, a shoemaker, and his wife, Beata. In 1806, the family moved to Pall Mall in London, where the elder Wheatstone became a music teacher; his pupils included Princess Charlotte. Charles attended several private schools, finding the experience uncomfortable because of his chronic shyness. At the age of fourteen, he was apprenticed to his uncle, also named Charles Wheatstone, who had a business in the Strand manufacturing musical instruments. The young Charles found that experience as uncongenial as school and returned home, immersing himself in books—including a treatise on electricity by Alessandro Volta, which he translated from French with the aid of a dictionary.

Wheatstone's brief experience of working with his uncle cultivated a fascination with acoustic science and made a considerable impression when he exhibited an "acoucryptophone," or "enchanted lyre." The instrument suspended from the ceiling played by itself as if by magic, though it was actually resonating with the sounds (transmitted by wire) of musical instruments played in another room. The idea occurred to him of using electrical wires to carry signals over much longer distances, making broadcast music possible. Though it never came to fruition, the idea inspired him to coin the term "telephone" to describe such a device. His coinage "microphone," describing a device for augmenting feeble sounds—what would nowadays be called an amplifier—also failed to catch on.

When Charles Wheatstone the instrument maker died in 1823, his nephew William took over the business, and the young Charles returned to the Strand, apparently feeling able to work with his older brother. He published a paper in the *Annals of Philosophy* on his early experiments with sound, and he developed a "kaleidophone," in which a bead suspended on the end a steel wire was caused to describe elaborate patterns of movement in harmonic response to different patterns of vibration in the wire. In 1825, he designed a mouth organ whose reeds were controlled by a small keyboard. On June 19, 1829, Wheatstone took out one of his very few patents, on a bellows-driven concertina, which remained a familiar instrument throughout the twentieth century. He also developed a portable harmonium, which won him a prize at the Great Exhibition of 1851.

On the basis of his experiments in acoustics—and his first significant contribution to acoustic theory, published in the *Philosophical Transactions of the Royal Society* in 1833—Wheatstone was offered the post of professor of experimental philosophy at King's College in London. This proved to be a crucial career move; as a lecturer, he was a disaster, unable to adapt to public speaking, but he made very productive use of the college's laboratory facilities, becoming one of Great Britain's first notable academic research scientists.

LIFE'S WORK

In 1835, Wheatstone read a paper on "The Prismatic Analysis of Electric Light" to the annual meeting of the British Association for the Advancement of Science. The paper paved the way for a means of detecting minute proportions of metals in alloys by the spectroscopic analysis of electric sparks. The method, deployed by other researchers, ultimately revealed the existence of the previously undiscovered metals rubidium and thallium and helped astronomers determine the composition of stars. In 1836, he was elected a fellow of the Royal Society. In 1838, he discovered the principle of stereopsis, or binocular vision, and invented a stereoscope to combine two-dimensional pictorial images so as to give an impression of depth. Wheatstone's stereoscope, which used mirrors as well as lenses, was subsequently simplified by David Brewster. Wheatstone also invented a "pseudoscope," which had a contrary effect, making three-dimensional objects seem flat.

Like many other researchers, Wheatstone began experiments in telegraphy when the machine developed by Baron Pavel Schilling was widely demonstrated in 1836. On February 27, 1837, Wheatstone met another researcher in that field, William Fothergill Cooke, and was persuaded to go into partnership with him. Wheatstone, as an academic researcher, had intended to make the results of his own work freely available, but Cooke wanted to make a fortune. When Wheatstone had solved the problem of long-distance transmission, the partners were able to produce their first workable system, patented on June 10, 1837.

The first Cooke-Wheatstone telegraph used five signaling needles to set up sufficient signal combinations to encode the twenty-six letters of the alphabet. They developed a two-needle model in 1838, but it was still too cumbersome to be economically viable. The American inventor Samuel F. B. Morse had been a year behind them in filing his initial patent, but his rapid adoption of a binary code developed in Germany by Carl August von Steinheil enabled him to develop a single-needle system first. It was not until Cooke and Wheatstone began using a single-needle apparatus in 1845 that their system be-

THE ENCHANTED LYRE

There is no single invention whose description can summarize the awesome breadth of Charles Wheatstone's achievements. Still, his acoucryptophone (Greek for "hearing a hidden sound"), better known as the enchanted lyre, offers eloquent testimony to his inventive ingenuity.

The principle of sonic resonance had been known for more than two thousand years, but the idea of using a wire to transmit the sonic impulses required to produce sounds—including pieces of music—at a distance had not occurred to anyone before Wheatstone produced his seemingly magical instrument. In September, 1821, at the age of nineteen, he demonstrated his acoucryptophone at his father's shop in Pall Mall, London. A replica of an ancient lyre was suspended from the ceiling by a brass wire that connected to the soundboards of instruments—a harp, piano, and dulcimer—being played in the room above. To visitors, the lyre appeared to play on its own, though it was in fact just a sounding box. Wheatstone's device attracted attention from scientific circles and the general public. Although it was a simple device, primarily interesting as an amusement, the enchanted lyre demonstrated how sound waves travel more readily through solids than air.

came economically viable. It was then quickly adopted by all the railway companies in Britain. In 1841, however, Cooke and Wheatstone had fallen out over the question of who was primarily responsible for the invention. The matter was referred for arbitration to Sir Marc Isambard Brunel and Professor John Frederic Darnell, whose carefully mediated decision that Wheatstone and Cooke were equally responsible satisfied neither of the contending parties.

The argument between Cooke and Wheatstone flared up again when Cooke set up the Electric Telegraph Company in 1846. A parliamentary commission had to be appointed to sort out various claims for compensation, including one from Alexander Bain. Cooke's patents were eventually bought by the company for £120,000, while Wheatstone only received £33,000; Wheatstone then refused to have anything further to do with the company. The dispute heated up again when Cooke published a combative pamphlet in 1854 entitled *The Electric Telegraph: Was It Invented by Professor Wheatstone?* Wheatstone's reply prompted further assertive publications from Cooke.

In the meantime, Wheatstone continued to produce new devices for use in the context of telegraphy. In 1840, he developed a dial telegraph; in 1841, a type-printing telegraph. He also developed an automatic transmitting and receiving system independently of Cooke. Wheatstone became very interested in submarine telegraphy and conducted a significant series of experiments in Swansea Bay in 1844 with the collaboration of J. D. Llewellyn. He also worked in cryptography, developing a cipher that he named for his friend Lord Playfair; the Playfair cipher was still in use by the British army in World War II, although a method for cracking it had been developed earlier in the twentieth century.

Wheatstone's work in other fields included contributions to the development of the electrical generator, including the combination of armatures so as to produce a continuous current. He developed several devices for managing electrical resistance, including the rheostat. Ironically, the Wheatstone bridge for measuring and balancing electrical currents was only rediscovered by him in 1843, having been invented by Samuel Hunter Christie in 1833. Wheatstone also developed an ingenious method of measuring the velocity of electricity in a wire, using a spark gap and a rotating mirror, but obtained the wrong result, producing a figure in excess of the velocity of light. The "chronoscope" he invented in 1840, which measured minute intervals of time, proved more successful. A "polar clock" he invented for measuring time by the Sun, even when the Sun was obscured by cloud, was of little practical value but was also ingenious.

On February 12, 1847, Wheatstone married Emma West, the daughter of a Taunton tradesman, in Christchurch, Maylebone; they had two sons and three daughters. Although the flow of his inventions abated somewhat thereafter, his reputation continued to grow, especially among fellow scientists who thought that he had been shabbily treated by Cooke. He received honorary doctorates from the universities of Oxford (1862) and Cambridge (1864). He was knighted on January 30, 1868, a year ahead of Cooke. His reputation was international, and he was highly regarded in France. He was appointed a Chevalier of the Legion of Honor in 1855 and became a foreign associate of the French Academy of Sciences in 1873. He was in Paris when he died during an attack of bronchitis in 1875, but his body was shipped home so that he could be buried in Kensal Green Cemetery. Although Cooke made far more money in telegraphy than he did, Wheatstone managed his rewards much more wisely; he left an estate worth £70,000, while Cooke—like Alexander Bain—died penniless.

IMPACT

Wheatstone's achievements were somewhat confused, and perhaps blighted, by disputes over priority. It was inevitable, however, when electrical science was in its infancy and hundreds of researchers were working on the same conspicuous problems, that different researchers would make similar discoveries independently. His reputation outshone those of his detractors in his own day, and most subsequent historians have sided with him for two reasons. First, he was a shining example of zeal and skill in turning scientific theory into practical technology on a prolific and wide-ranging scale. Second, and perhaps more important, he never set out to exploit any of his discoveries commercially with the kind of ruthlessness that William Fothergill Cooke demonstrated; he was interested in discovery for its own sake and was always as ready to lend his work to others as he was to borrow from them. The manner in which he used the opportunities provided by his professorship at King's College provided an important new model of the raison d'être of academic scientists.

—*Brian Stableford*

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See also: Alexander Bain; Alexander Graham Bell; Emile Berliner; William Fothergill Cooke; Thomas Alva Edison; Elisha Gray; Oliver Heaviside; David Edward Hughes; Guglielmo Marconi; Samuel F. B. Morse; Werner Siemens; Alessandro Volta.

ELI WHITNEY

American mechanical engineer and manufacturer

Whitney is credited with inventing the cotton gin, a machine that separated cottonseed for the short-staple cotton fiber. He is also credited with devising a method by which muskets could be manufactured with interchangeable parts.

Born: December 8, 1765; Westboro, Massachusetts
Died: January 8, 1825; New Haven, Connecticut
Primary fields: Agriculture; military technology and weaponry
Primary inventions: Cotton gin; musket manufacture using interchangeable parts

EARLY LIFE

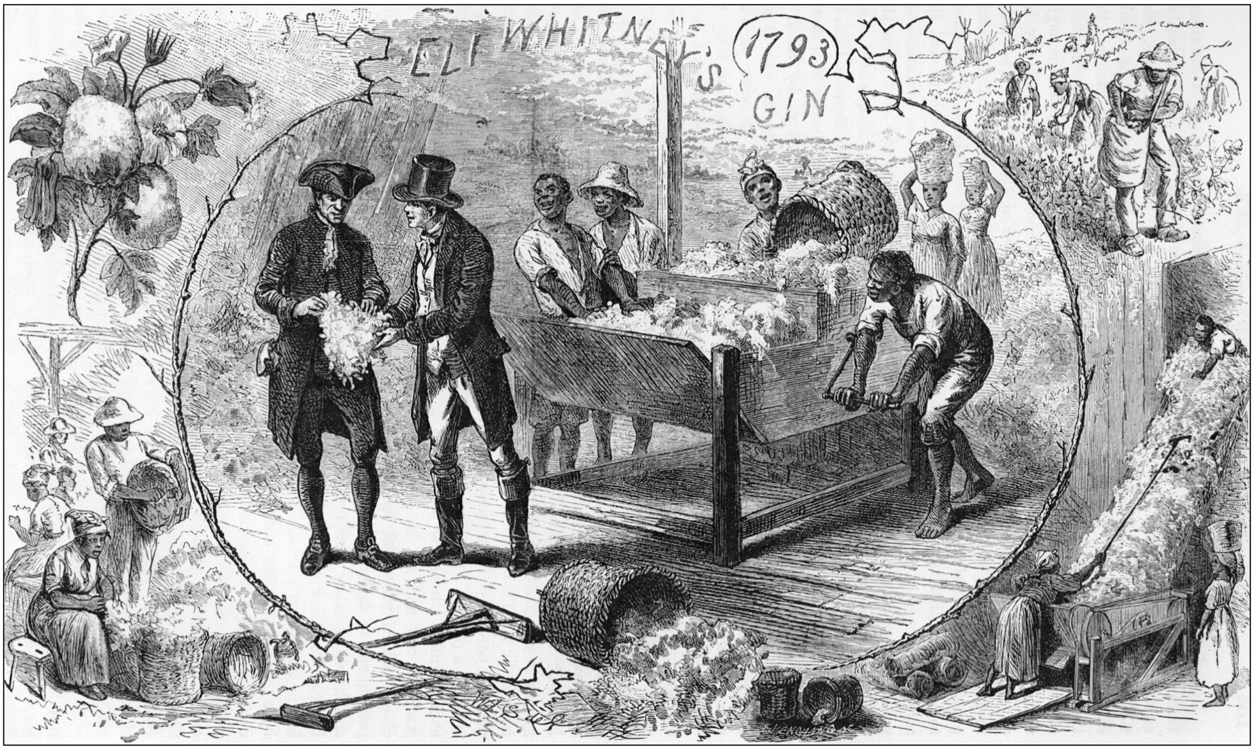
Eli Whitney was born on the family farm in Westboro, Massachusetts, in 1765. As a young man, he worked on the farm and as a blacksmith. When Whitney was fifteen years old, his father purchased tools for him that the boy used to build a nail-making machine. Later, Whitney made hat pins and walking sticks. While he was discouraged from going to college, Whitney saved money he made from the profits of the product he sold and from the income he made teaching in a village school. At the age of twenty-three, Whitney moved to Durham, Connecticut, to be tutored by the Reverend Elizur Goodrich. In May, 1889, Whitney was accepted to Yale University. Three years later, he graduated Phi Beta Kappa from Yale.

Whitney obtained a job as a private tutor in Georgia. Before moving there, he was inoculated against smallpox, but he contracted a severe case of the disease. When he finally traveled south, he met Catherine Greene, the widow of Revolutionary War hero Nathanael Greene. She invited him to stay at her plantation near Savannah while he recovered from his illness. It was there that Whitney's career as an inventor began to develop.

LIFE'S WORK

When Whitney moved south, cotton was not a major American commodity. Most cotton was grown in India and manufactured into products in England. These products were then imported to the United States, where they were considered luxuries. Cotton production was also a labor-intensive process. It took a worker approximately one day to separate one pound of short-staple cotton from seeds.

Whitney, working with plantation manager (and fellow Yale graduate) Phineas Miller, set up a workshop for the purpose of creating a machine that would separate the cotton staple from its seed. By 1793, Whitney had invented a cotton engine, or cotton gin, that accomplished



Eli Whitney's cotton gin not only made cotton production more efficient but also led to increased demand for slave labor in the American South. (C. A. Nichols & Company)

this feat. Whitney received a patent for his invention on March 14, 1794. He then created a business partnership with Miller and moved back to New Haven, Connecticut, to set up a factory to manufacture the machines. Their original plan was to establish their own ginning mills throughout the South where demand existed and to charge farmers for cleaning their cotton. Within the factory, Whitney utilized an approach whereby each worker would make only one part of the gin, such as the crank or the spindle, in order to assemble them faster. However, he encountered numerous problems in the manufacturing process ranging from a lack of skilled labor to a lack of materials such as wire. As a result, the partners were unable to keep up with the demand for the machines. In addition, patent infringement became a major problem, and within two years there were two variations of Whitney's cotton gin being produced and sold by others. Finally, in March, 1795, Whitney's factory was destroyed by fire, and within two years his cotton gin manufacturing company was out of business. Whitney finally secured a legal ruling in 1807 that protected his patent, but it was too late to save his business. In 1812, he was denied a patent renewal for his invention.

Whitney's next manufacturing venture entailed the production of firearms. Until 1797, the U.S. Department of War had armed its military with weapons left over from the Revolutionary War. At that time, gun making was considered a complex craft, with each gun being produced by a single craftsman. Production was slow, and the best American arms producers had never built more than three thousand muskets per year. Despite the fact that he had never manufactured firearms, Whitney bid on a contract to supply forty thousand muskets to the Department of War. In January, 1798, he received a contract to produce ten thousand muskets. Under the terms of the contract, Whitney was to deliver four thousand muskets within one year and the other six thousand within two years.

Whitney then built a firearms factory at Mill Rock, Connecticut, where he had purchased a grist mill in order to have running water for his machinery. Using his experience with the cotton gin plant, he set up a new manufacturing process using water-driven machinery, a division of labor, and interchangeable parts for the muskets. This approach to arms production was revolutionary, and Whitney did not initially grasp or appreciate the implications of utilizing this new manufacturing technique. He experienced numerous problems tooling up for this new process, and he had to design and make much of the machinery for his factory himself. He also had to train his own labor force to use this new equipment and technique. In addition, he had to develop a method for contracting supplies and having them delivered in advance of their need for the production process. As a result, Whitney did not meet his contractual deadline.

In 1801, Whitney persuaded President John Adams and the military that his innovative system of manufacturing uniform parts would work. He was granted an extension on his contract. While production was slow, Whitney delivered the last of the ten thousand muskets in January, 1809, ten years after the initial contract was drawn.

Whitney died on January 8, 1825. His factory continued to be operated by his nephews. In 1841, his son, Eli Whitney, Jr., graduated from Princeton University and assumed control of the factory. He soon received a contract from the federal government to manufacture twenty thousand rifles. Later, he manufactured the Whitneyville Walker Colts for the Texas Rangers. Over time, the factory was used by a variety of industries. In 1979, the Eli Whitney Museum and Workshop was established as a nonprofit historical site in New Haven, Connecticut.

IMPACT

Whitney is best known for his invention of the cotton gin. This invention had a tremendous impact on the economic, political, and social life of the United States, both North and South. As a result of this invention, cotton became the most important crop in the agricultural economy of the South. There was a ready market for cotton in Europe, and this resulted in the growth of the textile industry in New England. Finally, the increased demand for cotton resulted in an increased demand for slaves to grow the crop, and the economy of the South became more dependent on a slave-based system. Politically, the divisions between North and South increased as cotton became king and slavery became more entrenched, eventually leading to the Civil War.

Whitney also made significant contributions to the manufacturing process in the United States through other inventions and innovations. He invented the filing jig, which guided the worker's file. He designed a stencil with as many as twelve holes, which helped bore in exact places. He developed mechanical stops for his lathe to ensure that pieces were precisely turned. He also built the first milling machine, which precisely shaped metal parts, and he developed gauges in order to assure the uniformity of parts. Whitney not only built the tools but also developed the machines that used water to power the tools. His use of interchangeable parts revolutionized the small-arms industry, and, over time, these production techniques were applied to many different objects made of metal moving parts. These included bicycles, clocks, watches, sewing machines, typewriters, and, in the twentieth century, the automobile. Whitney's inventions and

THE COTTON GIN

Eli Whitney was an inventor, innovator, and entrepreneur in the manufacturing process in the United States. He is credited with the invention of the cotton gin, a device that had a significant impact on American history and politics. While Southern planters could easily separate long-staple cotton from its seeds, that cotton could be grown only along the immediate coastal region of the country. Short-staple cotton, which was grown inland, had sticky seeds that were difficult to separate from the cotton bolls. The cottonseeds had to be removed by hand. The cotton gin Whitney invented in 1793 was the first device able to clean the short-staple cotton. This machine consisted of spiked teeth mounted on a boxed revolving cylinder that pulled the cotton fiber through small openings that separated the seeds from the lint. Then, a rotating brush, operated by a belt and pulleys, removed the lint from the projecting spikes. This device could clean up to fifty-five pounds of cotton a day. Originally, the cylinder was turned by a crank. Later, the gins were powered by horses or water.

Whitney's cotton gin transformed the agrarian economy of the South. The cotton gin greatly increased the production of cotton by lowering the cost of the product. Cotton production doubled each decade after 1793, and cotton soon became the number-one-selling textile. By the middle of the nineteenth century, the United States was producing 70 percent of the world's supply of cotton. Sixty percent of the United States' exports came from the South, most of which was cotton. The cotton gin also contributed to the growth of slavery in the South as cotton farming became more profitable in the interior part of the South and Southwest. Large plantations were created throughout the South, and the institution of slavery expanded. The number of slave states increased from six in 1790 to fifteen by the middle of the nineteenth century, and approximately one of every three southerners was a slave.

innovations contributed greatly to the economic development of both the American South and North. Because of his accomplishments, he is considered, along with Thomas Alva Edison and Alexander Graham Bell, one of the most notable American inventors of the eighteenth and nineteenth centuries.

However, while Whitney is remembered by most people for his invention of the cotton gin, he also made significant contributions to the manufacturing process. When Whitney secured his contract to produce muskets for the federal government, he spent two years building and equipping a factory. He designed and built machine tools for the production of muskets using interchangeable parts, and he recruited and trained an unskilled workforce to use those tools. He even built houses for the workers to live in near his factory. He also had to develop techniques for procuring supplies in a timely manner. Whitney's innovations revolutionized the manufacturing process and the system of industrialization in the United States.

—*William V. Moore*

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See also: John Moses Browning; Samuel Colt; Richard Gatling; James Hargreaves; Thomas Jefferson; Cyrus Hall McCormick; Max Tishler.

SIR FRANK WHITTLE

British American aviation engineer

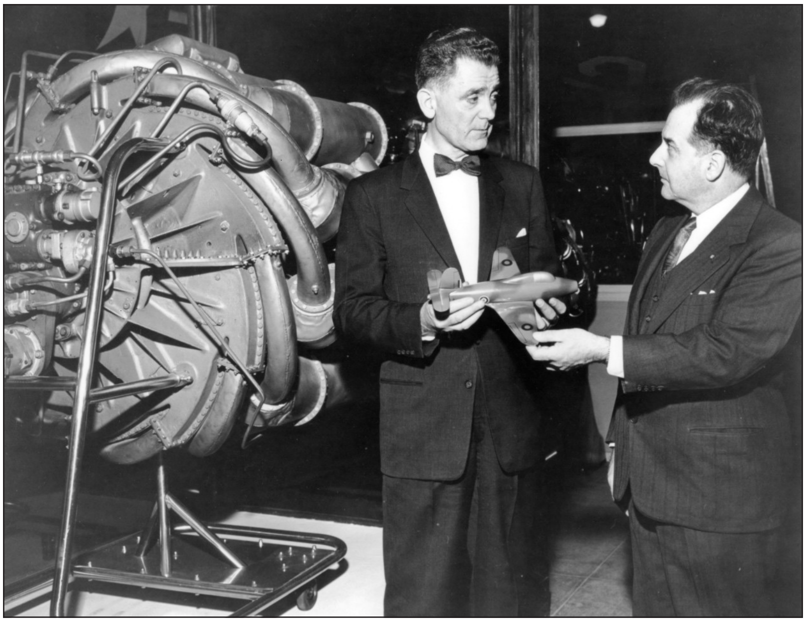
Whittle designed and built the engine that revolutionized aviation and ushered in the modern age of the jet aircraft. His engine has been called the greatest engineering development ever to occur in aviation.

Born: June 1, 1907; Coventry, Warwickshire, England
Died: August 8, 1996; Columbia, Maryland
Primary field: Aeronautics and aerospace technology
Primary invention: Jet engine

EARLY LIFE

Frank Whittle was born in Coventry, England, to Moses Whittle, a mechanic and inventor. As a child, Frank's favorite toy was a model Blériot airplane powered by a clock spring and suspended from the ceiling, where it would fly in a circle above his head. He was fascinated by airplanes and was especially excited when a local pilot made a forced landing near his home. Frank began his education at the age of five at Earlsdon Council School. Coming from a working-class background, he had somewhat limited educational opportunities. When he was nine years old, his father moved the family to Leamington Spa, where Moses purchased the Leamington Valve and Piston Ring Company. Young Frank was enrolled in the Milverton Council School and was awarded a scholarship to Leamington College for Boys.

The end of World War I had a negative effect on his father's income. Because of the family's reduced economic circumstances, Frank was not able to take advantage of a scholarship to a grammar school. He was not proving to be an outstanding student, and he decided to enlist in the Royal Air Force (RAF) as a boy apprentice. His first two attempts at enlistment were unsuccessful because of his small stature. On his third attempt, he neglected to mention the previous rejections and was accepted as a mechanic apprentice at the age of sixteen. He did very well in classes and displayed an aptitude for engineering. In 1926, he was accepted for flight training, in which he proved to be a very competent pilot. He also became somewhat of a daredevil, a trait that was to cause him some difficulty during his military career. By 1930, he was a fighter pilot, test pilot, and a flight instructor. On May 24, 1930, he married Dorothy Mary Lee.


Sir Frank Whittle, left, stands by a turbine engine he designed for use in Great Britain's first jet-propelled aircraft. (Smithsonian Institution)

LIFE'S WORK

By 1928, Whittle had become interested in the problem of high-speed flight at high altitude. He observed that, although a plane could fly faster at high altitude because of the decrease in atmospheric pressure, that same pressure decrease caused piston engine and propeller performance to degrade. He began writing his thesis "Future Development in Aircraft Design," in which he proposed alternatives to piston-powered, propeller-driven aircraft. He theorized that high-speed, long-range flight would require aircraft to fly at very high altitudes. At these altitudes, air pressure and drag would be reduced relative to the speed of the aircraft. He argued that propeller efficiency was the major limiting factor for this type of operation and that it required some type of jet propulsion. He completed this thesis at the age of twenty-one.

Whittle designed an engine with a turbine that would turn the compressor. The high-pressure gases not used to power the compressor would be expelled as thrust. He theorized that this type of engine would not suffer from performance loss due to the reduced air pressure. Whittle would spend the next thirteen years fighting for acceptance of his ideas.

In 1929, Whittle presented his work to the Air Ministry, which rejected his ideas as overly optimistic and impractical. The ministry questioned the existence of materials that could handle the extremely high temperature and rotational speeds required for the engine to operate. The ministry also concluded that Whittle's performance estimates were grossly in error. Nevertheless, Whittle was awarded a patent on May 24, 1930. He contacted a number of private manufacturers in the hope of generating financial support, but no company was willing to make the sizable investment required. Persevering in the attempt to generate interest in his project, he wrote a paper for the Royal Aeronautical Society on superchargers outlining his radical ideas for a new type of compressor. This was followed by another paper that dealt with gas turbines. None of this effort was rewarded, and it was not until 1936 that Whittle obtained a limited amount of support.

During this period, Whittle continued to perform his duties as an RAF officer. While he could gain no official sponsorship for his project, his initiative and ability were recognized by the Air Ministry. In 1932, he graduated from the officers' engineering course and was posted to Cambridge University to study mechanical sciences. Engineering had replaced flight as his primary passion. Throughout this period, he continued to refine his ideas, although he was still unable to build the engine.

In 1936, a small group of former RAF pilots suggested to Whittle that they form a corporation. The partners secured a bank loan to begin operations. That year, Power Jets, Ltd., was born and work on the jet engine began in earnest. The Air Ministry approved Whittle's involvement as chief engineer but restricted his activities to a maximum of six hours per week. The company eventually received limited support from British Thomson-

The Turbojet Engine

Sir Frank Whittle was the man who solved the problem of jet propulsion. Rather than utilizing a propeller to accelerate a mass of air, he designed a turbojet engine. It consisted of a double-sided centrifugal compressor rotating in excess of 17,750 revolutions per minute, which drew in large quantities of air, approximately 1,500 pounds of air per minute. This generated a tip speed of 1,500 feet per second with all of the associated stresses. The compressor generated an air pressure equivalent to four atmospheres and routed this high-pressure air into a series of ten combustion chambers mounted around the engine core, where fuel was introduced and ignited. The heated and compressed air accelerated through a single-stage turbine wheel whose blades deflected the gases and provided the energy to rotate the turbine wheel. The turbine was connected by a shaft to the compressor, thereby rotating the compressor at the same speed. In this way, the accelerated gases extracted only enough energy to turn the compressor at the desired speed. The remaining energy supplied by the hot gases passed out through an exhaust nozzle in the form of thrust.

One of the major difficulties that had to be overcome was the manufacture of these components. They required materials that could withstand the heat and stresses produced by the engine. This resulted in the design and production of many high-strength stainless-steel alloys. It was believed that these alloys could not be welded successfully because of the requirement for very thin parts manufactured to extremely close tolerances. The combustion chamber, for example, was only 1⁄64 of an inch thick. Whittle proved that it could indeed be welded, and Power Jets became a leader in stitch welding of very thin exotic metals.

Whittle's engine differed in both design and function from all existing engines of the day. Unlike reciprocating engines, his turbojet engines were efficient at altitudes up to about forty thousand feet. This altitude was unachievable by a propeller-driven aircraft. By relying on the acceleration of gases rather than a propeller to produce the thrust, Whittle eliminated the problem of loss of efficiency at high altitude and high speeds. The use of a high-speed turbine wheel to turn a compressor that in turn supplied high-pressure air in tremendous amounts for combustion was the radical part of Whittle's theory that made efficient jet propulsion possible.

Houston (BTH), a company that manufactured industrial turbines. However, this was a mixed blessing: Whittle challenged some of BTH's design and manufacturing practices, and friction developed. Eventually, BTH traded its interest to Rolls-Royce. Even with the limited support of BTH and the Rover Automobile Company, adequate financing was lacking. In spite of these difficulties, Whittle and his dedicated team constructed the Whittle Unit (WU). On April 12, 1937, the first test run was undertaken. By June, 1937, Power Jets was almost entirely out of money and contemplating halting work on the engine.

The approach of World War II generated increased interest in Whittle's engine by the Air Ministry, which declared Whittle's project a high priority. In 1939, the ministry contracted for construction of a flight engine. This engine was installed in a specially built Gloster Pioneer aircraft. The aircraft made its first flight on May 15, 1941, and proved so successful that the government committed to production. Unfortunately for Whittle and his team, the British government decided that Power Jets be relegated to research and testing, while production was to be handled by the established aircraft engine manufacturing companies, primarily Rolls-Royce. Power Jets was ordered to surrender all pertinent drawings and materials. Whittle and his team eventually resigned, and Power Jets faded from existence.

Whittle had dedicated his life to developing his engine, and he had succeeded in spite of numerous obstacles, only to have the fruits of his labor stripped away. However, Whittle continued to be an active participant in aviation. He was knighted in 1948 and ended his career holding twenty-seven different patents, having worked as a technical adviser to British Overseas Airways Corporation (BOAC), Shell Research, Bristol Siddely Engines, and as a research professor at the U.S. Naval Academy. The "father of jet propulsion" died in Columbia, Maryland, on August 8, 1996.

Impact

Whittle was a visionary who refused to become discouraged when he could find little support for his ideas. His design of the jet engine was so revolutionary that few could fully comprehend the concept, much less see the potential consequences of such a design. Even the professor who read his thesis admitted that he could not fully understand it but could find nothing wrong with it. At a time when the fastest military fighter aircraft operated at a speed of about 150 miles per hour at twenty thousand feet, Whittle was envisioning speeds in excess of 500 miles per hour at much higher altitudes. While it took thirteen years to demonstrate conclusively that his radical ideas were indeed valid, the technology he invented completely revolutionized aviation.

Whittle developed the first jet engine for the Royal Air Force, and he was sent to Boston to work with the General Electric Company to produce an engine for the United States. Whittle was again successful, and his work resulted in the production of the first jet-powered fighter aircraft in the U.S. inventory, the Bell XP-59A Airacomet, which flew on October 2, 1942. Civil air transport owes a similar debt to Whittle, as jet engines now power virtually all of the large commercial aircraft. One man's dogged determination and persistence truly changed the face of aviation. The jet engine was the most significant technological development of the World War II era, and it was entirely the product of one man's vision.

—*Ronald J. Ferrara*

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See also: Glenn H. Curtiss; Hans Joachim Pabst von Ohain; Burt Rutan; Andrei Nikolayevich Tupolev.

OTTO WICHTERLE

Czech chemist

Wichterle discovered the hydrogel polyhydroxyethyl methacrylate (poly-HEMA), a synthetic polymer (plastic) that could absorb and retain water, and developed a method for molding it into flexible, soft contact lenses. He patented dozens of types of plastics and methods for their use or manufacture, and he wrote extensively on organic and inorganic chemistry, polymer science, and medical uses for plastics.

Born: October 27, 1913; Prostějov, Austro-Hungarian Empire (now in Czech Republic)
Died: August 18, 1998; Sdradisko, Czech Republic
Primary field: Chemistry
Primary invention: Soft contact lenses

EARLY LIFE

Otto Wichterle (OT-oh VIHK-tur-leh) was the youngest of five children born to Karel, co-owner of a farm machinery plant, and Slávka, a well-educated housewife. When he was six years old, Wichterle nearly drowned after falling into an open sewer, and afterward remained ill; diagnosed with an enlarged heart, he was expected to die within the year. Thinking him too sick to attend school, his parents arranged for him to be tutored at home. Two years later, Wichterle seemed healthy enough to return to school; in 1922, at the age of eight, he passed entrance examinations that placed him in classes with children three years older than himself. Wichterle endured some bullying but quickly adjusted, becoming involved in school sports and taking music lessons in addition to his regular studies.

After graduating from high school, Wichterle planned to study mechanical engineering at the Czech Technical University in Prague, but a friend advised him that he would have more opportunity to do research, and to study with better scientists, in the university's chemical engineering department. In 1936, he obtained his Ph.D. in chemistry from the university and remained there as a lecturer until November, 1939, when the Germans occupied Czechoslovakia and closed all its universities.

SOFT CONTACT LENSES

Contact lenses, or contacts, are small, transparent disks worn directly on the cornea of the eye to correct vision by focusing light properly on the retina of the eyeball. Contacts can be worn as an alternative to eyeglasses to correct near- or farsightedness, presbyopia (aging of the eye), or astigmatism (an irregularly shaped cornea). Contacts can be used to reshape the cornea, correcting conditions that cannot be treated with conventional eyeglasses.

Scientists and inventors since Leonardo da Vinci (1452-1519) had imagined contact lenses; the first glass contact lens that could be used in the human eye was created in 1887 by German physiologist Adolf Eugen Fick (1829-1901). Later lenses were made from clear plastic, but these prevented oxygen from reaching the eye, until researchers developed new types of plastic that could be penetrated by oxygen.

Contact lenses are worn for cosmetic reasons, providing an option of correcting poor vision without eyeglasses. In addition to changing the wearer's appearance, contacts can give the user a wider range of vision and will not, as eyeglasses will, slide on the user's nose, cause pain at pressure points on the nose or ears, or steam up because of changes in temperature.

Soft contact lenses created using Otto Wichterle's methods are more popular than rigid, or hard, lenses because they are less likely to cause irritation by their movement over the surface of the eye, or to cause pain if airborne irritants come in contact with the eye or lens. Soft lenses also provide an option for wearers who find it difficult to adjust to using rigid lenses, which can be felt in the eye and can be uncomfortable for some time before the eye adapts to them. Soft lenses can be placed in, or removed from, the eye with greater ease and worn with greater comfort.

Soft contact lenses are sometimes worn to change the appearance of eyes that do not have the look of a normal eye, or simply to change the eye color for the wearer's enjoyment. It is even possible to create a temporary special effect with soft contact lenses, such as the look of a cat's eye.

A wide range of soft contact lenses have been developed, such as extended-wear lenses, which users can leave in their eyes while they sleep, and disposable lenses, designed to be worn for a single day, reducing the risk of infection that may develop when contacts are worn for extended periods.

LIFE'S WORK

Realizing that German forces were arresting university professors, Wichterle left the university but continued his research at the Baťa Chemistry Research Institute in Zlín, where he developed a method for spinning synthetic nylon fibers that could be used in textile production. After World War II, he returned to Czech Technical University and was appointed a professor of macromolecular chemistry there in 1949. Always concerned with the quality of education in chemistry, Wichterle soon clashed with the administration over his teaching methods, the subjects he covered in classes, and the very purpose of education.

In 1952, Wichterle, then on the faculty of Prague's new University of Chemical Technology, met by chance a government official who worked on finding medical uses for plastics. Their brief conversation inspired Wichterle with several ideas for using hydrophilic polymers (plastics that could hold water) as substitutes or enhancements for human tissue. Wichterle immediately filed a patent on these types of water-permeable plastics and their possible uses, including an idea that they could be used to make soft contact lenses.

The next year, Wichterle and his colleague Drahoslav Lim patented polyhydroxyethyl methacrylate (poly-HEMA) gel, a transparent plastic that was nearly half water. Wichterle worked with ways to form the gel into a usable contact lens and in 1957 was able to briefly wear a thick, ragged-edged prototype lens in his own eye.

The University of Chemical Technology's communist administration fired Wichterle in 1958, and he immediately was offered the directorship of a new research institution, the Institute of Macromolecular Chemistry, at the Czechoslovak Academy of Sciences. He was not allowed to continue his research on hydrophilic plastics at the institute, so Wichterle moved his project to a separate laboratory, where soft contact lenses with smooth edges were formed in glass molds, although the methods were time-consuming. In 1959, several patients were experimentally fitted with the lenses. Wichterle coauthored an article about his groundbreaking work with water-retaining plastics in the journal *Nature* in January, 1960; however, that year the Ministry of Health ceased funding for the project because the lenses could not yet be mass-produced.

Wichterle continued his research at home. Combining pieces of laboratory equipment taken from the University of Chemical Technology, parts from an erector set belonging to his children, and a generator from his son'sbicycle, he developed a method for "spin casting" the lenses, forming them from softened plastic on rotating molds. On Christmas Day of 1961, he tested four of his homemade lenses on hospital patients and found that, although their vision was not improved, the patients could wear the lenses easily and could at least see through them.

Wichterle upgraded his homemade equipment, replacing the bicycle generator with parts from a record player, and exposing the lenses to ultraviolet rays filtered through a piece of glass taken from one of his bookshelves. Between January and April of 1962, Wichterle and his wife, Linda, a physician, made approximately fifty-five hundred contact lenses. As these lenses were tested and government officials learned of the project's economic potential, Wichterle was invited to resume his research at the Institute of Macromolecular Chemistry. In 1963, looking for a way to manufacture contact lenses on the same type of machinery used to made rigid lenses, Wichterle created and patented a xerogel, a plastic that could be formed into lenses while dry, then allowed to absorb water.

In 1964, Wichterle traveled to the United States to promote the soft contact lens; as part of his presentation, he would take a soft lens from his own eye, drop it on the floor, step on it, put it in his mouth to clean it with saliva, and then replace it in his eye. In 1965, an American investment company, the National Patent Development Corporation (NPDC), partnered with Wichterle and were licensed to mass-produce soft lenses once the product and manufacturing process were perfected. In 1966, the NPDC licensed Bausch and Lomb to produce the lenses, and soft contacts were first offered to the American public in 1971.

In 1968, Wichterle became director of the Macromolecular Division of the International Union of Pure and Applied Chemistry and traveled extensively, looking for further medicinal applications for hydrogels. The same year, during the Prague Spring reform movement, Wichterle was among sixty Czech activists who signed the "Two Thousand Words" manifesto, a document of protest against Czechoslovakia's communist leadership. In August, 1968, the Soviet Union occupied Czechoslovakia; to avoid arrest, Wichterle left the country. He returned to Prague in September, only to be removed once again from his professional position.

Wichterle's activities and contacts were limited, and he continued working in isolation, receiving the International Eye Research Foundation Prize (1978) and the American Optical Society Wood Prize (1983). In 1989, at the age of seventy-six, Wichterle was elected president of Czechoslovakia's Academy of Sciences and received the American Society of Plastic Engineers Hyatt Prize (1989). He retired from the Academy of Sciences after three years. Wichterle died in his sleep in 1998 at the age of eighty-four, having suffered a heart attack and a stroke during the previous year.

IMPACT

Wichterle was a pioneer in his approach to pure and applied sciences, simultaneously developing scientific theories and practical applications. He also pioneered the idea that synthetic materials could be made to imitate living tissues and used for medical implants.

Inspired by chance to work with plastics for medical applications, Wichterle laid a foundation for future developments in biomedical materials. He persevered in developing his ideas in spite of academic rivalries, political opposition, lack of funding for research, and loss of personal income. In pursuit of a product that seemed to serve only cosmetic purposes, Wichterle produced contact lenses that could be used in situations where rigid lenses or eyeglasses were impractical; his brilliant and innovative use of materials at hand to manufacture thousands of prototype lenses proved that mass manufacture of the lenses was possible. Soft contact lenses are invaluable in professional sports, occupations that place wearers in humid or particle-heavy environments and in military operations where specialized headgear and equipment prevent the use of eyeglasses. At the time of Wichterle's death, an estimated 100 million people worldwide were using soft contact lenses.

—Maureen Puffer-Rothenberg

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See also: Wallace Hume Carothers; Stephanie Kwolek; Toyoichi Tanaka.

SHEILA WIDNALL

American aerospace engineer

The first woman to serve on the U.S. Joint Chiefs of Staff, Widnall became an internationally renowned expert in fluid dynamics who revolutionized the field with her work on aircraft turbulence, vortices, and spiraling airflows.

Born: July 13, 1938; Tacoma, Washington
Also known as: Sheila Evans Widnall (full name); Sheila Evans (birth name)
Primary fields: Aeronautics and aerospace technology; mathematics
Primary invention: Flexible tailored elastic airfoil section

EARLY LIFE

Sheila Evans Widnall was born the oldest of two girls on July 13, 1938, in Tacoma, Washington. Her father, Rolland John Evans, lost his Colorado ranch during the Depression and became a rodeo cowboy and ranch hand. He then worked as a foreman in the shipyards, while attending college. Later, he was a production planner for Boeing Aircraft Company and finally a teacher after earning a master's degree. Her mother, Genevieve Alice, was a social worker and juvenile probation officer.

As a child, Widnall became interested in mathematics and science. She helped her father with painting, rewiring, plumbing, and building projects. The family lived near McChord Air Force Base, so at an early age Widnall became fascinated with the airplanes that flew over her home.

From elementary through high school, she attended all-female Catholic schools and excelled in science and mathematics. In her junior year of high school, she won first prize for a science fair project on the radioactive decay of uranium. In September, 1956, Widnall entered the Massachusetts Institute of Technology (MIT). She was one of twenty women in a freshman class of approximately nine hundred. In 1960, she received her bachelor of science degree in aeronautics and astronautics. Only ten of the original twenty women graduated. During the summers of 1957-1959 and 1961, she worked for Boeing, and she spent the summer of 1960 at the Aeronautical Research Institute of Sweden.

Widnall stayed at MIT to earn a master of science degree in 1961 and a Ph.D. in 1964. From 1961 to 1962, she worked as a research staff engineer, and from 1962 to 1964 she was a research assistant in MIT's Department of Aeronautics and Astronautics. During these years, she met and married William S. Widnall, also an aeronautical engineer. They had two children, William and Ann.

THE FLEXIBLE TAILORED ELASTIC AIRFOIL SECTION

Practical applications of Sheila Widnall's theories emerged both in the design of equipment to evaluate the forces and in the design of technology to control them. One of the many challenges involved in the study of turbulence in fluid mechanics was the problem of being able to measure fluctuations in pressure under unsteady conditions. In 1970, with C. G. Heller, Widnall described the use of piezoelectric transducers to measure high-frequency force changes caused by airflow causing bending in an airfoil, rods, and bars. She continued this research, contributing to the design of wind tunnels used for testing at the Massachusetts Institute of Technology (MIT).

Widnall applied for a patent in 1992 jointly with her husband, William S. Widnall, as well as William Gorgen and Jeffrey Evernham, with the patent assigned to Flex Foil Technology, Inc. The patent was awarded in 1993, and research proceeded into specific ways of dynamically modifying the shape of the leading edge of blades moving through various fluids. The patent was written to cover many kinds of conditions and functions, with special attention to aircraft wings and stabilizers as well as other applications. Previous designs for flaps on the wings of aircraft required control mechanisms or pilot intervention to change the angle of the flaps by rotating them from the points at which they are joined to the larger structures, but the shapes of the flaps themselves were not changed.

The main advantage over previous rigid designs is that greater lift and side force can be gained by delaying the separation of the flow of the medium, therefore minimizing the effects of the turbulence. The desired flexibility can be achieved by using flexible material that can expand and contract around a stiff central spine. There can be axle cavities inside the skin of the devices to allow for changes in the geometry of the surface. In general, relative stiffness is distributed between the leading and trailing edges, spine, and various segments of the devices.

Widnall's revolutionary designs for the reduction of turbulence in moving through fluids, based on decades of research, have an incredibly broad range of applications. In both air and water, the vortices created near the sides and back of a blade or wing cutting through the given medium are sources of instability, vibrations, and noise. Controlling these disturbances increases the safety, fuel efficiency, flexibility, and durability of many types of vehicles, and increases the capabilities of air- and water-based turbines and fans, as well as provides more lift and control in all kinds of aircraft, including helicopters.

LIFE'S WORK

Immediately after receiving her doctorate in 1964, Widnall became an assistant professor in mathematics and aeronautics at MIT. In 1970, she became an associate professor, and then a full professor in 1974. From 1975 to 1979, Widnall was head of the Division of Fluid Mechanics; from 1979 to 1990, she was director of the Fluid Dynamics Laboratory. In 1988, she became the president of the American Association for the Advancement of Science. From 1992 to 1993, she served as the associate provost at MIT.

In 1993, she was appointed secretary of the Air Force, thus becoming the first woman to be in charge of a military branch. During this time, she was responsible for 400,000 active-duty forces and 185,000 reservists, as well as allocating and planning a $62 billion budget. In October, 1997, she stepped down from the Air Force post and resumed her teaching career at MIT. She took part in the Lean Aerospace Initiative, which determined that any enterprise must identify and create value in order to be successful. In November, 1998, she was appointed institute professor, the highest honor awarded to MIT faculty. There are only fifteen institute professors, who are considered the very best of MIT. They have the freedom to follow intellectual pursuits without the obligation to teach courses.

Widnall has become internationally known for her life's work—computational, analytical, and experimental—in aerodynamics. Her field is fluid dynamics, with a specialty in aircraft turbulence, vortex stability, and spiraling airflows, all of which affect the performance of aircraft, hydro-craft, and high-speed ground transportation vehicles. Testing these complex phenomena required very specialized equipment, including wind tunnels, which she helped to design as part of her work at MIT. The anechoic wind tunnel, which suppresses the reflection of sound waves, was used to study noise associated with aircraft that can make short vertical take-offs and landings, especially useful in military and emergency situations with minimal space for runways. Other wind tunnel experiments were used to test material surfaces used in aviation.

Widnall's theoretical and experimental work centered on the study of vortices in relation to fluid dynamics. In the course of this work, she found that waves would expand around rings in vortices. This phenomenon became known as the "Widnall instability," and it was an important breakthrough in her field. In particular, her research has encompassed unsteady lifting surfaces in aircraft, the effect of unsteady air forces on shaking cylinders under both subsonic and supersonic conditions, the separation of leading-edge vortices from slender delta wings, the aerodynamics of tip vortices, noise in helicopters, the stability of vortices, the aerodynamics of ground transport vehicles moving at very high speeds, unsteady hydrodynamic loads on supercavitating hydrofoils (hydrofoils that reduce drag by creating a large bubble of gas, usually air, inside a liquid, usually water), the stability of boundary layers, the turbulence in the wake of aircraft, and more. The instability and noise associated with the swirling vortices created at the trailing edges and ends of spinning helicopter blades was a special focus, since these phenomena impact the safety of the vehicle.

After the tragic loss of the *Columbia* space shuttle in 2003, Widnall served on the Columbia Accident Investigation Board, which made recommendations addressing both the technical and organizational issues that led to the disaster. She has served as a trustee, council member, board member, guest lecturer, and/or consultant for numerous foundations, academic institutions, corporations, and government agencies. She is also active as an author and has served as an associate editor for scientific journals, including the *Journal of Aircraft*, *Physics of Fluids*, and the *Journal of Applied Mechanics*.

IMPACT

Through her excellence as a scientist, researcher, educator, inventor, and writer, Widnall became a role model for women. In recognition of her encouragement of women in the sciences and engineering, MIT in 1986 awarded her the Abby Rockefeller Mauzé chair, an endowed professorship. She was inducted into the Women in Aviation Pioneer Hall of Fame in 1996. The Women's International Center (WIC) recognized her achievements with its 1998 Living Legacy Award. In October, 2003, Widnall was inducted into the National Women's Hall of Fame.

A world-famous pioneer in the field of aerospace engineering, Widnall holds three U.S. patents and is a prolific author who has published more than seventy scientific papers. Her inventions and discoveries are breakthroughs in dealing with aerodynamic noise, aircraft turbulence, and vortex instability for either air or water vehicles. Improved performance, safety, flexibility, and energy savings support advanced models for the twenty-first century. Her work has contributed greatly to understanding helicopter rotor blade noise generation and aerodynamics, and the deterioration of aircraft wave vortices. In November, 2002, *Discover* magazine named Widnall one of the fifty most important women in science, for her discovery of the Widnall instability, which had a profound effect on the field of fluid dynamics.

—*Alice Myers*

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Widnall, Sheila E., and Hanno H. Heller. *The Role of Fluctuating Forces in the Generation of Compressor Noise*. Washington, D.C.: National Aeronautics and Space Administration, 1972. This and other articles

coauthored by Widnall can be accessed online at http://naca.larc.nasa.gov/search.jsp. Illustrated and bibliography.

See also: George Cayley; Samuel Pierpont Langley; Bill Lear; Edwin Albert Link; Paul B. MacCready; Charles E. Taylor.

PAUL WINCHELL

American television entertainer

Though better noted as a television personality and entertainer than as an inventor, Winchell developed innovations that ran the gamut from dramatic medical breakthroughs to novelties to unobtrusive everyday articles. His greatest accolades came as a result of his invention of the artificial heart, which purportedly became the model for the Jarvik-7 heart.

Born: December 21, 1922; New York, New York
Died: June 24, 2005; Moorpark, California
Also known as: Paul Wilchin (birth name)
Primary fields: Entertainment; household products; medicine and medical technology
Primary invention: Artificial heart

EARLY LIFE

Paul Wilchin was born to Jewish Americans Sol and Clara (née Fuchs) Wilchin, who had apparently shortened their surname Wilchinski before their son was born. Paul was the second of three siblings, with an elder sister, Ruth, and a younger sister named Rita. His father worked as a tailor, and the family lived in modest rented accommodations on the lower East Side of Manhattan.

Winchell's childhood was troubled. He had an especially stormy, even physically and verbally abusive, relationship with his strong-willed mother, and he harbored extremely bitter feelings about this phase of his life for years to come. However, according to his own account, this seemed to serve, in the long run, as a spur that would motivate him to excel in defiance of the odds. In 1928, at the age of six, Winchell was stricken with polio but, undertaking intensive weight exercising, was able to survive without severe or permanent physical impairment. Among the personal obstacles he faced was an abnormal shyness, coupled with a speech impediment (stuttering and stammering), which he overcame by developing and honing his speaking style, finally succeeding to the point that he was able to master the art of ventriloquism.

In this effort, in which Winchell was almost entirely self-taught, he had as a hero and role model the famed celebrity ventriloquist Edgar Bergen, whose performances with his dummies Charlie McCarthy and Mortimer Snerd during the 1930's through the 1950's pioneered voice throwing as an entertainment form. Young Winchell's immediate source of inspiration came from attending a live performance of Bergen in New York. Begging money from his sister Ruth's boyfriend, Winchell was able to purchase a pamphlet on ventriloquism. He not only cured himself of his speech impediment but also (using dummies that he had learned to fashion with

Ventriloquist Paul Winchell, seen here with his puppet Jerry Mahoney in 1949, was also a prolific inventor. His artificial heart invention, patented in 1963, was donated to the University of Utah for research. (Getty Images) the help of his father) began making a name for himself by giving comedy ventriloquist routines for classmates and teachers.

LIFE'S WORK

Winchell's first true break into show business came in 1936, when his art school principal arranged for him to appear on the *Major Bowes Original Amateur Hour* radio show. It was then that he was first introduced under the professional name by which he would thereafter be known: Paul Winchell. (This was the idea of his sister Ruth's boyfriend, who believed that the pseudonym would make the young man's act more marketable to audiences.) Winchell's routine with his dummy, originally named Terry, was so well received that he won the cash prize and launched into his career as an entertainer. Taking part for several years in the vaudeville tour, he had the good fortune to be on hand for the advent of television.

One of the trailblazing shows of the early mass-media television era was *The Bigelow Show*, which ran on the Columbia Broadcasting System (CBS) and the National Broadcasting Company (NBC) networks from 1948 to 1949 and featured Winchell and his most famous ventriloquist dummy, Jerry Mahoney. From 1950 to 1968, Winchell performed, and usually starred, in children's and variety shows such as *The Spiedel Show*, *The Winchell-Mahoney Show*, and *Circus Time* with Jerry Mahoney and his second great dummy characterization, the slow but good-hearted Knucklehead Smiff.

Though Winchell was already one of the best-known names in the entertainment world, it was in 1962 that he diverged into a career as a voice-over artist. From 1968 to 1999, Winchell acted as the voice behind the animated cartoon character Tigger in the Walt Disney cartoon series *Winnie the Pooh*, the voice-over impression for which he is best known. Achieving great success, he branched into a series of voice-over roles as diverse as those of Dick Dastardly in *Wacky Races*, Gargamel in *The Smurfs*, Boomer in *The Fox and the Hound* (1967),

THE ARTIFICIAL HEART

A celebrity dance contest organized by dance impresario Arthur Murray set into motion a chain of events for noted TV ventriloquist-entertainer Paul Winchell. Winchell won the prime-time TV contest and at a subsequent reception at Murray's home met Dr. Henry Heimlich (who would later stake his own claim to fame as the originator of the lifesaving Heimlich maneuver). Out of this meeting came Heimlich's offer to Winchell—who was at that time also a medical student—to observe surgical procedures at New York's Montefiore Hospital. There, Winchell was deeply affected when a patient died on the operating table during heart surgery.

At Heimlich's suggestion, and with his technical advice and assistance, Winchell undertook the task of designing a model for an artificial heart that could sustain a patient through a complex surgical procedure by temporarily performing the heart's routine bodily functions. (Only later was the idea of a more permanent heart implantation seriously considered.) By Winchell's own account, the process involved was somewhat akin to the design and construction of some of the ventriloquist dummies that he had previously created, with comparable moving parts and compartments. Winchell's idea was based on the construction of a mechanically, externally driven substitute, or even replacement, heart, made of material such as nylon that would be durable and as noninvasive as possible. The device would have two internal chambers, the top chamber being capable of containing five ounces of blood; the lower one, four ounces. The blood would be circulated through the body by means of a special squeezing mechanism. The external motor mechanism was designed to be strapped and held in place to the patient's outer chest wall by means of a harness.

Winchell was granted a patent for his artificial heart design on July 16, 1963. Some nine years later, Dr. Willem Johan Kolff, director of the Medical Center for the Institute for Biomedical Engineering at the University of Utah, whose Division of Artificial Organs had been developing artificial hearts (which were then undergoing trials on animals), requested that Winchell donate his patent to the university. Winchell assented, handing over the patent on November 22, 1972.

Winchell, Heimlich, and others asserted that the University of Utah biomedical engineer Dr. Robert Jarvik largely borrowed from and refined Winchell's artificial heart design in creating the Jarvik-7 heart. The Jarvik-7 was first successfully implanted by a cardiovascular surgeon, William Castle DeVries, into a human recipient, Barney Clark, on December 2, 1982. The claims put forward by Winchell and Heimlich have been challenged in some quarters; it has been asserted that Jarvik's primary model on which he made the improvements that culminated in the Jarvik-7 device was an earlier powered model called the Kwann-Gett heart.

Fleegle in *The Banana Splits*, and Zummi in *Disney's Adventures of the Gummi Bears*. In 1974, Winchell received the Grammy Award for Best Recording for Children. He appeared in roles for various Hollywood productions, among them *Stop! Look! and Laugh!* (1960), *Vernon's Volunteers* (1969), *Which Way to the Front?* (1970), and *The Treasure Chest Murder* (1975), but these roles never became a substantial part of his career.

Winchell's career as an amateur inventor took him in many directions. He became a premed student at Columbia University. Studying there from 1959 to 1974, he ultimately earned his doctorate in acupuncture. He also became a proficient hypnotherapist, working part-time at Mount Vernon Hospital in New York. Dr. Henry Heimlich invited Winchell to observe and assist at Montefiore Hospital. There Winchell conceived the idea of an artificial coronary device that could be implanted during surgery and possibly increase the heart patient's chances of survival. Winchell completed his artificial heart device in 1956, when he applied for a U.S. patent, and was finally granted a patent on July 16, 1963 (U.S. Patent number 3,097,366). On November 22, 1972, Winchell donated the patent to the University of Utah's Institute for Biomedical Engineering. Dr. Robert Jarvik, who worked at the university, was said to have refined and adapted the model to develop his Jarvik-7 artificial heart. Thereafter, it appears that relations between Winchell and Heimlich on one hand and Jarvik and Dr. Willem Johan Kolff, Jarvik's department chair, on the other became strained. Over the ensuing years, a debate surfaced as to the extent of the influence exerted upon Jarvik's mechanism by Winchell's prototype.

Winchell filed for many other patents, including a retractable-tipped fountain pen (3,071,113, filed January 30, 1961); a jewelry pendant (D216371, November 27, 1968); an electric heater for a container (3,079,486, May 22, 1961); a lens cover (3,133,149, September 23, 1960); a warning indicator for interrupted power supply for freezers (3,063,225, February 3, 1961); a tandem sifter for flour and other products (3,063,563, January 30, 1961); an inverted novelty mask (3,129,001, May 22, 1961); a nonbulging garter fastener (3,128,477, February 3, 1961); a pouring expediter for sugar, salt, and the like (3,110,424, January 30, 1961); a nonvisible garter for hosiery (3,097,407, December 1, 1961); and a hand pump for transferring liquids (3,120,192, December 22, 1961). One prototype he developed, but for which he did not bother to file, to his later regret, was for the disposable razor.

During the 1970's, Winchell worked with alternative energy advocate Dr. Keith E. Kenyon of Northrop University on developing an electric motor for automobiles. The 1980's saw Winchell, Heimlich, Senator Ted Kennedy, and certain entertainment industry notables team up to form the Africa Tomorrow organization and to conceive a scheme whereby hunger in Africa might be alleviated by teaching Africans how to raise and harvest the prolific and hardy tilapia fish. However, they were unable to secure U.S. congressional support for its funding, and the project petered out.

Winchell married three times: His first marriage was to Dottie Morse (by whom he had two children, Stephanie and Stacy Paul); his second, to Nina Russel (the couple had a daughter named April Terri); and the third, to Jean Freeman (the mother by a previous marriage of two sons, Larry and Keith, whom Winchell adopted). His personal life was turbulent, though the full extent of this was not generally known until he published his controversial autobiography, *Winch*, in 2004. In the book, Winchell blamed his mother and his ex-spouses for most of his emotional and psychological problems. Some see the autobiography as an attempt to ease the painful memories that were still plaguing him. Others, and most openly his daughter April, took exception to this view and lay more of the responsibility on Winchell himself, alleging problems such as marital infidelity, verbal abuse, and fits of anger—and stating that Winchell as a family man was a far different persona than the television kid's show idol with whom most of the baby-boom generation was familiar. Apart from his autobiography, Winchell was the author of the books *Ventriloquism for Fun and Profit* (1954) and *Pressure Points: Do it Yourself Acupuncture Without Needles* (1979; with Kenyon). Toward the end of his life, he was active in the Universal Church ministry, establishing a Web site called ProtectGod.com (now defunct). On the night of June 24, 2005, Winchell died in his sleep of apparent heart failure.

IMPACT

Winchell's most revolutionary and enduring innovation is the artificial heart. However, debate continues over who should receive what amount of credit for the development of the device. It has been alleged that Robert Jarvik did not incorporate portions of Winchell's designs—nor did they even influence him—in the making of the Jarvik-7 artificial heart. Henry Heimlich consistently maintained that the design set forward by Winchell in the patent that he donated to the University of Utah was totally incorporated into the Jarvik-7 and that Jarvik himself must have been familiar with it. The question over the extent (if at all) to which Jarvik made use of Winchell's research has been bandied about long after Winchell's death and shows no sign of being resolved. Regardless, Winchell must rank as one of the most versatile, and unusual, inventive geniuses of the mid-to-late twentieth century, and a model to nonspecialists with avant-garde ideas.

—*Raymond Pierre Hylton*

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Winchell, Paul. *Winch: The Autobiography of Paul Winchell*. Bloomington, Ind.: AuthorHouse, 2004. Very straightforward, even brutal, in its style, this book offers excellent psychological insight into what drove Winchell to overcome his negative childhood experiences and persevere to become a successful entertainer. Discusses his invention of the artificial heart.

See also: King Camp Gillette; Robert Jarvik; Willem Johan Kolff.

ALEXANDER WINTON

American automobile manufacturer

Winton was a leading pioneer in the automobile industry, and his Winton Motor Carriage Company was one of the first American companies to sell automobiles. He also invented the first American diesel engine and the first engines with marine applications.

Born: June 20, 1860; Grangemouth, Stirling, Scotland
Died: June 21, 1932; Cleveland, Ohio
Primary fields: Automotive technology; manufacturing
Primary invention: Automobile components

EARLY LIFE

Alexander Winton was born in Grangemouth, Stirling, Scotland, to Alexander and Helen Fea Winton. He was a bright student and demonstrated mechanical talent at an early age. At age nineteen, he immigrated to the United States and worked for the first few years at the Delameter Iron Works in New York and in a factory making marine engines. These experiences gave Winton a practical education that remained with him throughout his life. At about age twenty-three, Winton moved to Cleveland, Ohio, where he lived for the rest of his life.

In 1891, Winton received his first patent, for a bicycle, and he organized the Winton Bicycle Company to manufacture his new invention. Although the business was successful, Winton was restless. After five years, he began to turn his attention to the creation of a new mechanical wonder that promised to revolutionize transportation: the automobile. He completed his first motorcar in 1896 and incorporated the Winton Motor Carriage Company in 1897.

LIFE'S WORK

Early automobile makers often tested their new machinery in what were called reliability (or endurance) tests. On July 28, 1897, Winton began the first reliability run in the United States by making a nine-day trip from Cleveland to New York. The trip attracted a great deal of attention and led to a sufficient amount of new investment that allowed Winton to build four new automobiles later that year. In late March, 1898, he sold his first car—believed to be the first automobile sales transaction in the United States for a standard-model gasoline-powered vehicle—to Robert Allison of Port Carbon, Pennsylvania. Allison decided to buy the car after seeing an advertisement in *Scientific American* magazine. Later that year, Winton sold twenty-one automobiles. One of these was sold to a future competitor, James Packard, whom Winton may have inadvertently pushed into the automobile business. When Packard complained about the performance of the car Winton had sold him, Winton challenged Packard to see whether he could do better. Packard went on to create the Packard automobile, which remained in production until the 1960's, long after the Winton automobile had ceased to be manufactured.

In 1899, Winton made a second, even better advertised, reliability run from Cleveland to New York, cutting the travel time almost in half by making the trip in just five days. This trip stimulated so much interest that Winton sold more than one hundred cars that year, making his company the largest manufacturer of gasoline-powered automobiles in the United States. This success in turn led Winton to authorize the first automobile dealership in the United States, opened by H. W. Koler in Reading, Pennsylvania, in 1899. In 1901, after ten years in the bicycle business while experimenting with automobiles on the side, Winton began to manufacture automobiles full time.

Winton also raced his automobiles. He pitted his cars against the first vehicles produced by Henry Ford, losing to Ford at Grosse Pointe, Michigan, in 1901 and vowing to improve in 1902. For the second match with Ford, Winton created a new vehicle, named the Bullet, which set an unofficial record of 70 miles per hour. Despite this achievement, Winton's driver was unable to best Ford's illustrious Barney Oldfield in the 1902 race. Winton built two more Bullet-type racing cars, which also failed to win. Nevertheless, racing remained an important form of advertising for automobile manufacturers.

Winton long worked to make his vehicles durable. In 1903, he cooperated with Dr. Horatio Nelson Jackson to stage what was then the ultimate reliability run: a trip across the United States from San Francisco to New York. Jackson and his mechanic made the journey in sixty-four days, which included time for breakdowns and the delivery of repair parts. These exploits enabled Winton to sell his custom-built upscale cars to the wealthy until the 1920's. These various models included five-passenger touring cars and a large limousine. One version of the limousine used an engine mounted in the middle of the vehicle. Although this design did not become standard for American automobiles, it was an indication of Winton's willingness to innovate.

Winton diversified, calling on his early training with marine transportation, by creating the Winton Engine Company in 1912 to manufacture marine engines. By 1913, Winton had produced the first diesel engine in the United States. This diversification was important because Winton's sales of automobiles declined in the 1920's and the Winton Motor Carriage Company stopped making cars in 1924.

Winton continued to manufacture various engines, including diesel and marine engines, until 1930, when he sold the company to General Motors, which turned it into the Winton Engine Corporation. As such, it created the first practical two-stroke-cycle diesel engines powerful enough to drive diesel locomotives and U.S. Navy submarines. In 1935, the section of the Winton Engine Corporation that made diesel locomotives became a part of the Electro-Motive Corporation, a division of General Motors that was still operating in the early twenty-first century. The remaining portion of the Winton Engine Corporation manufactured almost exclusively Navy, marine, and stationary diesel engines. In 1937, General Motors converted this into the Cleveland Engine Division, which continued operation until 1962.

Alexander Winton. (The Granger Collection, New York)

Winton was married and widowed twice. His first wife, Jeanie Muir McGlashan, bore him six children and died in 1903. Three years later, he married LaBelle McGlashan, with whom he had two more children before her death in 1924. In 1927, he married Marion Campbell, a marriage that ended in divorce in 1930. Finally, he married Mary Ellen Avery in 1930. Winton died in 1932 and was buried in the Lakeview Cemetery in Cleveland, Ohio.

IMPACT

Although Winton is not particularly well remembered today, he was a significant American automotive pio-

WINTON'S INNOVATIONS

The holder of more than one hundred automotive patents, Alexander Winton was a significant leader in the development of the automobile. Among his innovations were his brake and steering systems for automobiles. In 1901, Winton gave one of his complete steering mechanisms to Henry Ford because he was convinced that the system Ford was using was extremely dangerous. Ford used this innovation in the vehicle he manufactured to defeat Winton's car in one of their early races. Winton could take consolation in the fact that he helped advance automobile safety.

If the history of invention is that of one innovation building on another, this process is visible in Winton's lifelong career. Since the earliest automobiles were not much more than double bicycles with engines, Winton's first patent, for a bicycle innovation, presaged his later automotive career. His early employment at a company making marine engines led to a career in this field lasting longer than the three decades he spent making automobiles. His work on marine engines led to the development of the first American diesel engine, later developed to power the largest vehicles in the U.S. Merchant Marine and the Navy. Once such large diesel engines were available, they could be transformed into the power plants of railroad locomotives.

neer. With more than one hundred patents in automobile design, he clearly had a large role in the development of cars. Beyond the technical innovations, Winton popularized the industry with his auto racing and his reliability testing. The historic journey of Jackson driving a Winton automobile from San Francisco to New York went a long way toward creating the popular understanding that the automobile was not a toy but had the potential to become a prominent form of transportation. Winton's diesel engines were ultimately developed into the power plants for Navy warships and the Merchant Marine. Winton also should be credited for taking the first steps toward powering trains with diesel engines.

—*Richard L. Wilson*

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See also: Carl Benz; Nicolas-Joseph Cugnot; Gottlieb Daimler; Rudolf Diesel; John Boyd Dunlop; Henry Ford; Hiram Percy Maxim; André and Édouard Michelin; Ransom Eli Olds; Sylvester Roper; Felix Wankel.

GRANVILLE T. WOODS

American machinist and mechanical engineer

Woods invented many electrical and electromechanical devices related to railway technology and telecommunications systems. He also invented the egg incubator and improvements to inventions such as safety circuits, phonographs, telegraphs, and telephones. Altogether, he had approximately sixty patents to his credit.

Born: April 23, 1856; Columbus, Ohio
Died: January 30, 1910; New York, New York
Also known as: Granville Trey Woods (full name)
Primary field: Railway engineering
Primary invention: Synchronous multiplex railway telegraph

EARLY LIFE

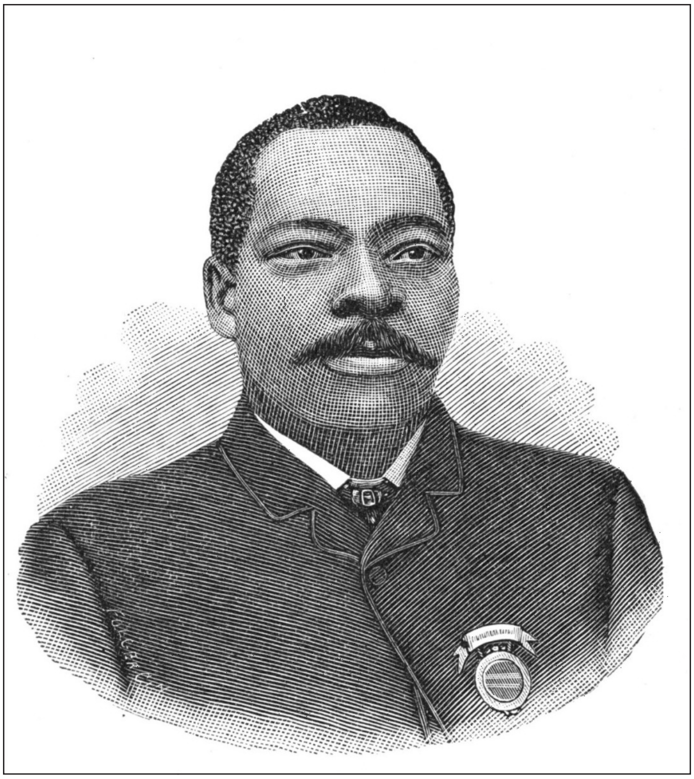
Granville Trey Woods, son of Tailer and Martha Woods, was born on April 23, 1856, in Columbus, Ohio. Because of the Northwest Ordinance, a law passed in 1787, he was born a free African American. Woods attended school until the age of ten, when he began a machine shop apprenticeship. He learned trades that enabled him to repair railroad equipment and machinery and to also work as a blacksmith. Intrigued by electrical power, Woods studied other workers as they dealt with different machines and paid those workers to teach him electrical concepts. To improve his academic skills, he also went to night school and took private lessons. Woods left Columbus when he was sixteen years old and traveled around the country working on railroads and in steel rolling mills. His academic and employment experiences helped to prepare him for formal engineering coursework. His natural talents, inquisitive nature, persistence, and determination prepared him for the life of a very productive inventor.

Although the Civil War had ended, certain areas of the United States were embroiled in racial turmoil. Many African American workers were unable to get lucrative factory jobs because they were undereducated, unskilled, or simply because of their skin color. Those who were qualified for such jobs were limited to a narrow range of careers and often prohibited from joining increasingly powerful unions. Woods sought ways to overcome racial barriers to his success.

LIFE'S WORK

In 1872, Woods began working as a fireman on the Iron Mountain Railroad in Missouri. He eventually became an engineer for that company. In his spare time, he studied electronics and experimented with electricity. In 1874, Woods moved to Springfield, Illinois, and worked in a steel rolling mill. In 1876, he moved eastward, worked six half-days in a machine shop, and took college courses in electrical and mechanical engineering during afternoons and evenings. In 1878, Woods took a job aboard the British steamer *Ironsides*, sailing around the world and ultimately becoming chief engineer of the steamer. Two years later, he obtained employment as a conductor of a steam locomotive with Danville and Southern Railroad. In spite of his increased education and experience, he was denied opportunities and promotions because of racial prejudice. He eventually realized that in order to successfully utilize his talents to the fullest, he would have to be self-employed.

Woods settled in Cincinnati, Ohio, in 1881. Three



Engraved portrait of Granville T. Woods, late 1800's. (Getty Images)

THE SYNCHRONOUS MULTIPLEX RAILWAY TELEGRAPH

One of the most important inventions developed by Woods Electric was the synchronous multiplex railway telegraph, a variation of the induction telegraph. The system was developed to improve communications between train crews and station dispatchers. To develop the synchronous multiplex railway telegraph, Granville T. Woods utilized one of the basic laws of physics and electricity, Faraday's law of electromagnetic induction. This law states that a current sent through a coil-shaped wire will generate a magnetic field around the coil. When a wire moves through the magnetic field, a current like that in the coil is induced in the wire. When the wire stops moving or when there is no current in the coil, no current is induced in the wire.

From inside a train car, an electric current from telegraph equipment passed through a coiled cable. The end of the cable was suspended underneath the train car and generated a magnetic field around the train car. As the train car traveled along the tracks, the magnetic field moved with it and induced a similar current in the telegraph lines already running along the tracks, even though the train cable and the telegraph lines were eight to ten inches apart and parallel to each other. The power of the induced current was strong enough to be received by the telegraph equipment at a nearby station or on other trains. In a similar manner, electrical currents generated by the telegraph at a train station and passed into the ground wire between rails could be picked up by the cable underneath the train car. This phenomenon of electromagnetic induction allowed station dispatchers to pinpoint the locations of all trains in their area at any given time. It also allowed train crews and dispatchers communicating with one another via telegraph to share details about oncoming trains and information about hazardous conditions. This communication helped make both commercial and passenger railways safer. The synchronous multiplex railway telegraph permitted two hundred telegraph operators to simultaneously use one wire. Although messages were going in opposite directions, they did not conflict with one another.

Although Woods received a patent for his special railway telegraph in 1887, his patent was challenged in court by two other inventors, Thomas Alva Edison and Lucius Phelps. Woods was declared to be the rightful patent holder and permitted to sell his patent to the Westinghouse Air Brake Company, which also specialized in electrical signaling. Unfortunately for Woods, much of the money he made from the sale of his patents went to pay legal fees rather than going into research and development at the Woods Electric Company. The Woods brothers eventually closed their business.

years later, he and his brother Lyates formed the Woods Railway Telegraph Company, which later became the Woods Electric Company. The company developed, manufactured, and sold telephone, telegraph, and electrical equipment. Among the company's first patented inventions were an improved steam boiler furnace and an improved telephone transmitter with superior clarity of sound and longer-range transmission.

In 1885, Woods patented a product that was a combination of a telephone and a telegraph, a "telegraphony." His invention allowed a telegraph operator to send either voice or telegraph messages over a single wire. The device was so successful that he later sold it to the American Bell Telephone Company. The lucrative sale enabled Woods to become a full-time inventor.

Woods patented a synchronous multiplex railway telegraph in 1887. A variation of the induction telegraph, it allowed for messages to be sent between moving trains, and between trains and railway stations. With this device, dispatchers could know the location of each train, telegraph information about equipment conditions and hazardous weather, and take necessary precautions to make railway travel safer. In the robust railroad industry of the late nineteenth century, this invention was so successful that Woods found himself fighting patent suits filed by Thomas Alva Edison and Lucius Phelps. Woods successfully defended himself, proving that there were no existing devices upon which he could have modeled his invention. Persistent in winning Woods and his expertise, Edison offered Woods a prominent position in the engineering department of Edison Electric Light Company in New York. Woods refused, preferring to remain independent.

As a prolific inventor, Woods soon developed other inventions for electric railways. His patents included electromechanical and electromagnetic brakes (1887), an overhead electrical conducting system for trolleys (1888), and an automatic safety cutout for electric circuits (1889). For a while, he manufactured and sold his inventions through the Woods Electric Company, but he later sold his patent rights to the General Electric Company.

In 1890, Woods moved to New York City to develop more electrical equipment for subways and trolleys. In collaboration with his brother Lyates, he patented emergency braking systems and devices relating to third-rail power. Woods used his knowledge of electrical systems to devise the method of supplying electricity to a train without any exposed wires or secondary batteries. Approximately every twelve feet, electricity would be passed to the train as it passed over an iron block. In 1892, he demonstrated the device as a complete Electric Railway System at Coney Island amusement park in New York City. The Woods Electric Company closed in 1893, but Granville Woods continued working to meet the need for more electrical products.

At the turn of the century, Woods patented an air brake, an egg incubator, and devices for regulating and controlling electrical devices and motors. He continued to develop and patent better railway systems and equipment during the last decade of his life. When he died on January 30, 1910, at Harlem Hospital in New York City, he had become an admired and well-respected inventor, having sold many patents to such corporations as Westinghouse Air Brake Company, General Electric, American Bell Telephone, and American Engineering.

IMPACT

Many of Woods's inventions attempted to increase efficiency, safety, and profitability of the burgeoning railway communications, commerce, and industry of his time. Because he explored the many advantages and possibilities in utilizing clean electrical energy over horse power, coal, and steam, he is among the forerunners of modern proponents of environmentally friendly energy sources.

Over the course of his lifetime, Woods obtained approximately sixty patents for his inventions, including an electromechanical brake, an electromagnetic brake, an automatic air brake, an electrical railway system, and an egg incubator. He also had patents for improvements to other inventions, such as safety circuits, telegraphs, phonographs, and telephones. Among Woods's better-known contributions are inventions introducing third-rail electrical power in mass-transit subway systems and overhead electrical power for trolley cars. Many subway, elevated, and commuter-rail systems still use third-rail electrical power. His development of the synchronous multiplex railway telegraph system allowed messages to be sent to and from moving trains, enabling train conductors and engineers to avoid collisions and to report information about hazardous conditions. This invention is one of the forerunners of modern communications networks. Woods is among the inventors who have inspired creative integration of science, engineering, and technology to solve a variety of business and industrial problems.

Woods struggled as a relatively small businessman encountering opposition from big corporations with competitive advantages. Although selling some of his patents yielded him initial profits, Woods came to realize that a product sometimes resulted in higher-than-anticipated demand. Yet because he sold his patents, he received no additional profits and little if any public recognition for their development. Even when challenges to his patents forced him into legal disputes, Woods demonstrated the fortitude needed to consistently defend his patent rights.

Granville T. Woods overcame many obstacles related to being an African American genius and a prolific inventor during an era when most African Americans could obtain neither a basic education nor viable employment. Public schools in New York City, Chicago, and suburban New Orleans were later named in his honor.

—*June Lundy Gastón*

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See also: Alexander Graham Bell; Thomas Alva Edison; Michael Faraday; Lewis Howard Latimer; Samuel F. B. Morse; George Westinghouse.

STEVE WOZNIAK

American computer engineer

Wozniak produced several key technical innovations of the microcomputer era, including chip designs and circuit boards that used electronics more efficiently than previously thought possible.

Born: August 11, 1950; San Jose, California
Also known as: Stephen Gary Wozniak (full name)
Primary field: Computer science
Primary inventions: Personal computer (PC); *Breakout* (video game)

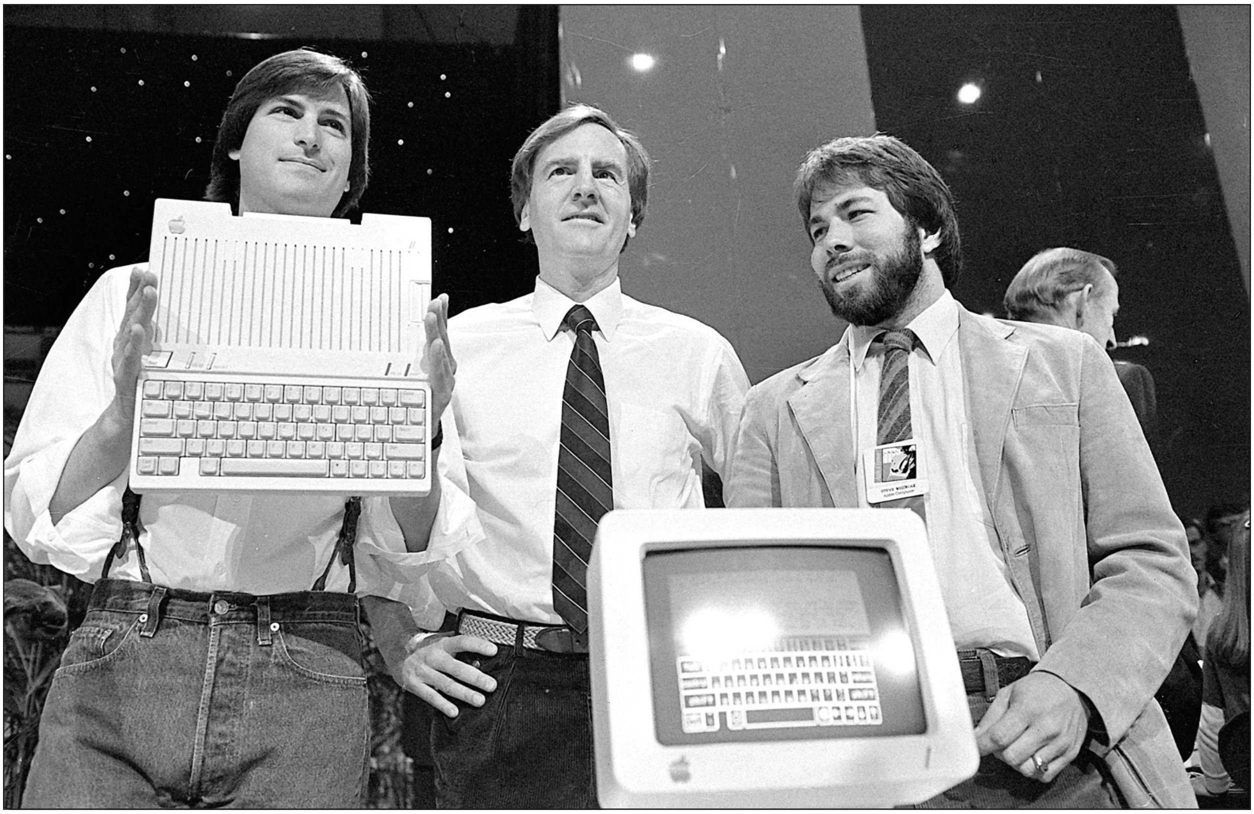
EARLY LIFE

Stephen Gary Wozniak (WOZ-nee-ak) was born in San Jose, California, the son of an electrical engineer. His father, Jerry, worked for the National Aeronautics and Space Administration (NASA) and other government agencies during Steve's childhood. When young Steve asked his father questions about work, the elder Wozniak would always answer that he was a man of his word. Steve eventually figured out that his father was working on secret projects and had promised not to talk about them. This understanding instilled in Steve a powerful ethic of honesty.

However, the young Wozniak differentiated between lies and pranks. His nimble technical mind allowed him to come up with very complex pranks that could even fool adults. For instance, he once designed a very convincing fake bomb using two old-fashioned stick batteries and an electronic oscillator that produced a realistic ticking sound. When he planted it in a friend's locker, intending to startle the unwitting friend, he instead created a panic. The school principal, thoroughly convinced that the device posed a deadly threat to his students, scooped it up and sprinted to the football field, where he disassembled the device. Wozniak was quite surprised to be arrested and put in juvenile hall for his prank, since he regarded it as an example of his skill with electronics rather than anything truly dangerous.

While still in high school, Wozniak got an internship at GTE Sylvania, a company producing microwave relay systems for telephone networks. There he worked with his first computer, an IBM 1130 mainframe that ran on punch cards and occupied a case the size of a refrigerator. Wozniak appreciated the privilege of being able to work with this computer; the experience taught him to move beyond purely hardware approaches and to understand the importance of the instructions that made a computer work. (The term "software" was relatively new at that time.) He learned FORTRAN, one of the earliest computer languages, and how to write programs for the 1130.

After dropping out of the University of Colorado, Wozniak met a new friend, Steve Jobs. The two young men shared interests and, like many computer geeks, considered technical know-how the currency of status within their subculture. The two men soon became in-



From left: Steve Jobs, chairman of Apple Computer; John Sculley, president and chief executive officer; and Steve Wozniak, cofounder of the company, unveil the new Apple IIc computer in San Francisco, California, in April, 1984. (AP/Wide World Photos)

volved in phone phreaking, building "blue boxes" to spoof telephone switching systems and gain free calls. Once they had a close call with a suspicious police officer, but Jobs convinced him that the illegal device was a music synthesizer.

LIFE'S WORK

In 1973, Wozniak left school to get a job with the electronics company Hewlett-Packard (HP). A year later, Jobs found work with the video game manufacturer Atari. Jobs was asked to design a new game, *Breakout*, and soon pulled Wozniak into the work, agreeing to split the money. In fact, Jobs had been promised a hefty bonus for certain design features, which he quietly pocketed. Wozniak would not find out about this for more than a decade, when he was helping a researcher write a history of Apple Computer (later Apple). Wozniak was not so upset about the money—he would have done the job for free just to be able to work on such an intellectual challenge—but the deception and betrayal stung bitterly.

At the time, Wozniak was simply happy to have successfully completed the challenge. He became involved in the Homebrew Computer Club, a group of computer hobbyists, in his spare time, and he designed an innovative microprocessor-based machine, originally to impress his friends. However, Jobs saw commercial potential in it, and both men sold a personal prized possession to raise capital: Wozniak, his HP programmable calculator; Jobs, his Volkswagen bus. On April 1, 1976, they officially founded Apple Computer, and a few months later they delivered their first shipment of assembled circuit boards to the Byte Shop, an early Silicon Valley computer store.

Their first computer's relatively crude appearance appealed only to dedicated hobbyists, so Jobs and Wozniak designed a successor, the Apple II, which came in a tan plastic case, in order to appeal to the general public. Wozniak did most of the circuit design, while Jobs concentrated on developing Apple's new logo, a rainbow-colored apple with a bite out of it. When users of the earliest Apple II model complained about the slow loading of programs from cassette tapes, Wozniak designed a controller for a floppy disk drive, and the Apple II became one of the first microcomputers to boast floppy disks. The Disk II system allowed the Apple II to run business programs.

When Jobs launched the Macintosh project, Wozniak was instrumental in developing the disk controller for it, the Integrated Wozniak Machine (IWM) chip. However, the discovery of Jobs's betrayal over the *Breakout* money and other issues with Jobs's management style drove Wozniak away from the company he had helped found. Still, he remained active in the electronics industry, developing such diverse items as the first programmable universal television remote control and wireless Global Positioning System (GPS) equipment. He concentrated largely upon practical devices that help improve the lives of ordinary people.

Wozniak also became involved in various charitable causes and social activities. He sponsored two US Festivals, free concerts held in Southern California in 1982 and 1983. He used his engineering expertise to work out a realistic approximation of how many portable toilets would be needed for the expected attendance. He also made both financial and intellectual contributions to the Children's Discovery Museum in San Jose. The street in front of the museum was subsequently renamed Woz Way in his honor.

Wozniak was an early adopter of the Segway personal transport, and he became involved in a game known as Segway polo, showing that his quirky sense of humor has not diminished as he has aged. The top prize in this new sport is the Woz Challenge Cup, named in his honor. His sense of humor and good nature were underscored by his appearance as a competitor on the television talent show *Dancing with the Stars* in 2009.

BREAKOUT

The earliest video game was *Pong* (released in 1972), an adaptation of table tennis, or Ping-Pong, in which players used handheld controllers to move rectangular "paddles" back and forth on a television screen in order to bounce the ball back and forth. The primitive state of electronics at the time made it impossible for programmers to create a computer-controlled player, so a single person wanting to play alone was out of luck. This was a minor annoyance for owners of the home console but represented a considerable amount of lost revenue for arcade owners.

Thus, Atari founder Nolan K. Bushnell was interested in developing a single-player version of the game. He visualized something like handball, in which the player would bounce the ball off the walls, but that seemed rather simplistic. To add additional challenges for the player, he suggested that the object of the game would be to remove several rows of colored bricks by striking them with the ball.

Bushnell initially turned to Steve Jobs, who was working as one of his technicians at the time. Seeing that the task was beyond his skills, Jobs recommended Steve Wozniak, who was skilled in circuit design. Wozniak gladly took the challenge and soon produced a design that used far fewer chips than anything else Atari had produced. However, his design was so elegant that it was difficult to manufacture, and it had to be modified in order to allow the chip-fabricating technology of the time to produce it.

In spite of its relative simplicity (the original *Breakout* had only two screens of bricks, and once all of them were knocked out, the player could advance no further), the video game quickly became a hit at video arcades across the country. Atari took the revenue to design more advanced versions of *Breakout* that included a potentially infinite number of screens of bricks, as well as increasing challenges as the game went on. For instance, the on-screen paddle would shrink after a certain number of levels were cleared, or the ball would begin moving more rapidly.

As a result of these changes, new versions of *Breakout* became open-ended. In one *Breakout* version, the ball smashed through whole rows of bricks instead of destroying a single one with each bounce. Other variations added narrative elements or additional complications. For example, *Arkanoid*, popular in the late 1980's as both an arcade game and a computer game, was built around a story of a spaceship full of refugees fleeing an enemy and having to make its way through a series of fields of hostile aliens. In this game, each level's field of bricks was arranged in a different way, and some of the bricks produced "pills" that gave special power-ups. At the top of the field were two "gates" that would open to admit small aliens that could destroy the player's on-screen paddle if they touched it. *Arkanoid* also replaced the open-ended format with a set collection of thirty-two fields and a thirty-third round in which the player had to kill the master alien by bouncing the ball off its one vulnerable point, at which point a victory screen was displayed.

Because the basic form of *Breakout* is so simple, the game was later included as a surprise, or "Easter egg," in a number of computer programs. It later became available in numerous forms as shareware, often as a desktop application.

IMPACT

Although Wozniak was less interested in business than was his friend and collaborator Steve Jobs, his technical expertise was critical in the founding of Apple Computer and its early success, even into the Macintosh era. He designed computers that needed fewer chips than previous models, and his simple, elegant designs laid the groundwork for future product lines.

—*Leigh Husband Kimmel*

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See also: Nolan K. Bushnell; Bill Gates; Ted Hoff; Steve Jobs.

FRANK LLOYD WRIGHT

American architect

Wright is considered by many to be the greatest architect of the twentieth century. During his long career, he was responsible for a great many innovations in structure, materials, and design.

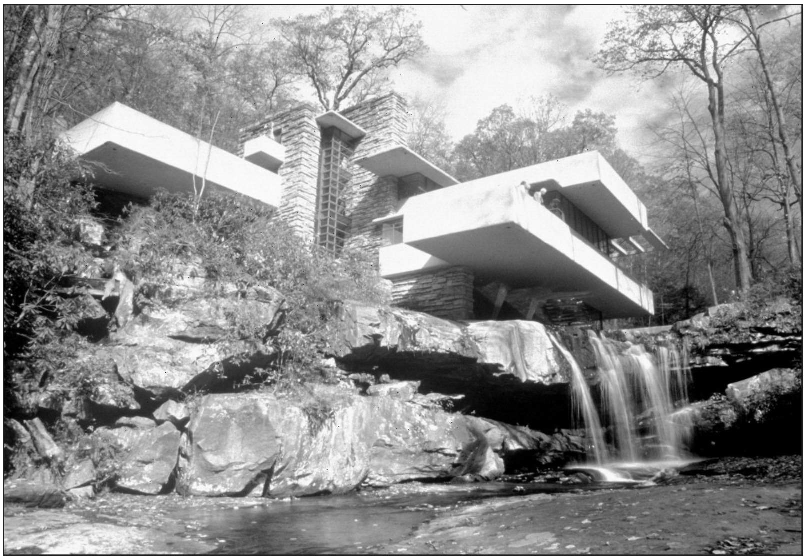
Born: June 8, 1867; Richland Center, Wisconsin
Died: April 9, 1959; Phoenix, Arizona
Also known as: Frank Lincoln Wright (birth name)
Primary field: Architecture
Primary inventions: Innovative architectural design (open planning, outdoor rooms, water features) in such signature projects as Taliesin, Fallingwater, the S. C. Johnson building, and Usonian and Prairie homes

EARLY LIFE

Frank Lloyd Wright was born in Richland Center, Wisconsin, on June 8, 1867, and given the middle name of Lincoln. Frank's mother, Anna Lloyd Jones Wright, was a schoolteacher and the daughter of prosperous Welsh immigrants. Frank's father, William Carey Wright, was a New Englander who became a Baptist preacher. In 1863, William's first wife, Permelia, died in childbirth, leaving three children. Three years later, William and Anna were married.

Though William was likeable and dynamic, he was impractical; he kept accepting calls to churches that could not pay him enough to support his growing family—for Frank was soon joined by two younger sisters. After three years in Richland Center, William moved to McGregor, Iowa; Pawtucket, Rhode Island; and Weymouth, Massachusetts. In 1877, he accepted a call to a Unitarian church in Madison, Wisconsin. William's indifference toward Anna and his children by her made her understandably hostile toward him. In 1885, William and Anna were divorced. William left Madison, and Frank never saw his father again. About this time, Frank changed his middle name to Lloyd, thus claiming his mother's family and her Welsh heritage.

Despite the family problems, Frank had a relatively happy youth. He always had playmates and friends. Moreover, his mother, who was always certain that he would be a great architect, devoted a great deal of time to his education. She utilized the progressive ideas of the German educator Friedrich Wilhelm August Fröbel, who believed in balancing physical and mental activity,



Fallingwater, designed by architect Frank Lloyd Wright as a weekend cottage for Edgar J. Kaufmann, is an example of organic architecture. The house sits above the falls and blends with the environment. (AP/Wide World Photos)

encouraging creativity through the use of geometric designs, and developing a reverence for nature. Though Frank attended the Second Ward Grammar School in Madison, his real education took place at home, where he could let his imagination run free, reading, painting, drawing, or just dreaming. In order to toughen him up physically, every summer from 1878 on Wright was sent to work on an uncle's farm.

Since his father would not support Anna and her children, Frank dropped out of Madison High School in March, 1885, and began working in an architectural office. He also attended the University of Wisconsin for two semesters, but in the spring of 1887 he went to Chicago, which had become an important architectural center.

LIFE'S WORK

At his first job, in the drafting office of the architect J. Lyman Silsbee, Wright began to develop skill in domestic architecture. His employer's high estimate of Wright is evident in the fact that within a year, he was making enough to bring his mother and his younger sister, Maginel Wright, to live with him in suburban Oak Park. On his own time, he built the Hillside Home School in Spring Green, Wisconsin, for two of his aunts. Wright then obtained a position with Adler and Sullivan, an architectural firm that was always on the cutting edge of design. There he worked on the massive Auditorium Building, thus expanding his knowledge of engineering. He also learned a great deal from Louis H. Sullivan, who was noted for his innovative designs. Sullivan thought so highly of Wright that he made the young man his assistant.

On June 1, 1889, Wright married Catherine Lee Tobin, and they moved to a house in Oak Park that he had designed and built for her. The next year, their first child was born; five more would follow. As the family expanded, Wright built onto his home. A spacious playroom constructed in 1895 had a floor patterned with the shapes Wright remembered from his Fröbel training; its extensive use of natural light and its open plan foretold designs to come.

In 1893, Wright left Sullivan and formed a partnership with his friend Cecil Corwin. Three years later, Wright became independent. He constructed a number of low, horizontal homes in and near Oak Park that became known as "Prairie houses." In them, he eliminated interior walls as much as possible, substituting large open spaces with multiple uses; he also used porches to eliminate the break between indoors and outdoors. These ideas would reappear in his designs for larger homes and even for public buildings such as the Larkin Administration Building in Buffalo, New York (1902-1906), and the Unity Temple in Oak Park (1905-1908).

However, Wright's marriage had collapsed. In 1909, he eloped to Europe with a married woman, Mamah Borthwick Cheney. After they returned, Wright installed his mistress at Taliesin, the house at Spring Green that was to be his home, his studio, and later the location of his Fellowship. On August 14, 1914, tragedy struck. Without warning, a newly hired cook ran amok, killing seven people, including Mamah and her two children, and setting fire to the living quarters, which burned to the ground. Wright was devastated. His only salvation was his work.

Wright had already begun planning one of his most ambitious projects, the Imperial Hotel in Tokyo (1922). Aware of the danger of earthquakes, he designed the building in separate sections, each of which was attached to a base that floated on the mud below, and he also placed pools of water throughout the structure, thinking that they could be useful in case of fire. The Imperial Hotel was one of the few buildings in Tokyo to survive the catastrophic 1923 earthquake.

During the years that followed, Wright designed and built "Usonian homes" for people of modest means; lavish private residences like Fallingwater in Bear Run, Pennsylvania (1935); and public structures such as the S. C. Johnson and Son Administration Building in Racine, Wisconsin (1936), and the Solomon R. Guggenheim Museum in New York City (1959). At a rebuilt and expanded Taliesin, he founded the Fellowship, a system in which students, or apprentices, pursued their artistic interests while living a communal life. He later added a second campus, Taliesin II, located in the Paradise Valley near Phoenix, Arizona.

After Mamah's death, Wright had become involved with Miriam Noel, a sculptor. However, he postponed obtaining a divorce from Catherine until 1922. His subsequent marriage to Miriam lasted only a few months. In 1928, Wright married Olgivanna Ivanova Lazovich Hinzenberg, a dancer from Montenegro. They had one daughter, Iovanna. Wright died in a Phoenix hospital on April 9, 1959, and was taken to Wisconsin to be buried in the family graveyard. However, after Olgivanna died in 1985, Iovanna insisted that her mother had wanted Wright to be buried with her. His body was exhumed and cremated, and his ashes were taken to Taliesin West.

Impact

Though during his lifetime a great many architectural fashions came and went, Wright paid little attention to them. Instead, he drew his inspiration from his own inner sense of what was good and beautiful. This freedom from tradition, from fashion, and indeed from all outside influences enabled him to invent structures that were totally new and different—an office building without separate cubicles, for example, or a house with a concealed entrance. Wright could also use whatever materials he wished in whatever combination he liked. He could place something as modern as reinforced concrete in close proximity to traditional building materials like wood or stone and produce a structure that seemed at the same time as ancient as its

Fallingwater

Fallingwater, a house Frank Lloyd Wright built in 1935 in Bear Run, Pennsylvania, has been called the most famous private residence in the world. It was commissioned by Edgar J. Kaufmann, the president of a Pittsburgh department store, and was intended as a weekend retreat, where his guests would have a good view of the falls. However, Wright had his own vision of what the building should be. In keeping with his theory of organic architecture, Wright decided to build the house over the falls, making it appear to jut out from the rocky slope over which the falls flow so that it would seem to be an integral part of its natural surroundings. Not surprisingly, this unusual structure cost some $75,000, or $40,000 more than the limit that Kaufmann had originally set.

Fallingwater reflects both the horizontal and the vertical planes of the site. Two cantilevered terraces cross above the falls, mirroring the horizontal ledge over which the water flows, while the tall chimney that rises above the massive stone fireplace echoes the vertical lines of the waterfall. Some of the natural materials Wright used were local; the Pottsville sandstone, for example, came from a quarry near Harrisburg, Pennsylvania. However, Wright also paid tribute to the new technology, for example, by utilizing reinforced concrete for his pillars.

The floor plan of Fallingwater exemplifies another of Wright's theories: that the interior space in a house should make confinement or separation almost impossible. There are very few walls in the house. Most of the first floor is taken up by a huge living and dining room. The bedrooms on the second and third floors are relatively small; much of the space on those floors is taken up by large, stone-paved terraces.

Unfortunately, Fallingwater was so far ahead of its time that some of the materials and the techniques that would have made it more stable were not yet developed. Over the years, the original owner's son, Edgar Kaufmann, Jr., did his best to maintain Fallingwater. In 1963, he presented the house and the land around it to the Western Pennsylvania Conservancy. By the 1990's, it was evident that a major overhauling was necessary. The most urgent task was to repair the concrete cantilevers, which were threatening to collapse because they had not been sufficiently reinforced; in addition, the house needed to be rewired and new heating and plumbing systems installed. With these and other repairs completed, Fallingwater was once again secure.

In 2000, the American Institute of Architects voted Fallingwater the Building of the Century. However, though Fallingwater is a unique architectural achievement, it has also influenced the direction of domestic architecture. Many home buyers now look for a house that suits its site, that has an open plan, and that uses expanses of glass, outdoor rooms, and terraces to bring the outdoors in. Thus, Wright's ideas, as embodied in Fallingwater, have become accepted by ordinary Americans.

natural surroundings and as new as the spacecraft of the future.

Wright's genius was also evident in the fact that he never repeated himself. Every building he designed was unique, and as decade followed decade, he was constantly pursuing new paths, while at the same time remaining true to those principles by which he had always been guided, among them his insistence on fitting a structure to its site.

Wright's designs are responsible for much that is taken for granted today: for example, open planning, outdoor rooms, and the use of water features in homes, hotels, and convention centers. His works and the free spirit that produced them continued to influence both domestic and commercial architecture throughout his life span and into the twenty-first century.

—*Rosemary M. Canfield Reisman*

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See also: Robert Hooke; Thomas Jefferson.

WILBUR AND ORVILLE WRIGHT

American aeronautical engineers

The Wright brothers developed the first successful heavier-than-air flying machine that incorporated wings to create lift; propulsion to produce forward thrust; and movable surfaces to control pitch, roll, and yaw, thus making modern aviation possible.

WILBUR WRIGHT

Born: April 16, 1867; near Millville, Indiana
Died: May 30, 1912; Dayton, Ohio

ORVILLE WRIGHT

Born: August 19, 1871; Dayton, Ohio
Died: January 30, 1948; Dayton, Ohio
Primary field: Aeronautics and aerospace technology
Primary invention: First successful heavier-than-air aircraft, the Wright Flyer

EARLY LIVES

Wilbur and Orville Wright were born in 1867 and 1871, respectively, to Milton and Susan Koerner Wright. Wilbur was born near Millville, Indiana, shortly before the Wright family moved to Dayton, Ohio, where Orville was born. They had five brothers and sisters. Their father was a bishop in the United Brethren Church; he was a strong, self-confident man who believed utterly that, with enough hard work, a person could achieve anything he or she set out to do. He encouraged his children to explore whatever made them curious. Wilbur and Orville often credited this early environment with allowing them to pursue their passion, flying, and with giving them the work ethic to persist until they were successful.

Wilbur was an outstanding student, and there were plans to send him to Yale. However, when he was eighteen, he was struck in the face by a stick during a game of hockey. He lost several teeth, and he also developed a heart condition. Whereas he had been an outgoing young man before the accident, after it he became withdrawn and very quiet. He did not attend college, instead choosing to stay at home and nurse his mother, who subsequently died of tuberculosis in 1889. Upon her death, Wilbur and Orville's sister Katharine took over the task of caring for the family. Except for the four years she spent at Oberlin College, she was a homemaker for Orville, Wilbur, and their father, a role she continued for Orville until 1926, long after the deaths of Wilbur and her father.

Wilbur (left) and Orville Wright. (Library of Congress)

Orville did not finish high school. During his junior year, he left school to open his own printing business, publishing his first newspaper in 1889. Wilbur joined him in this endeavor; although the newspaper business failed quickly, the print shop prospered. At about the same time, however, the brothers became interested in bicycles, and soon they were not only riding bikes but also repairing bicycles for their friends. In 1892, the brothers founded the Wright Cycle Company, and they were very successful in this venture. In 1899, however, they began work on what became the passion of their lives: the quest for flight.

LIVES' WORK

Across the world, many engineers and scientists were racing to develop the first heavier-than-air flying machine. In Europe, Otto Lilienthal was the best known, and his work with hang gliders aroused intense public scrutiny. In 1896, however, one of his gliders went into a stall, and Lilienthal crashed to the ground, mortally wounded. His work, and his death, aroused the interest of the Wrights. In their search for information, they contacted the Smithsonian Institution and received books and brochures describing the work of two Americans, Samuel Pierpont Langley, the head of the Smithsonian Institution, and Octave Chanute.

The brothers recognized almost at once that the key to solving the problems of mechanical flight were threefold: They would need sturdy yet flexible wings to provide lift; they would need some sort of engine to provide forward motion, or thrust; and they would need to be able to control the machine in flight. The Wrights were careful engineers who were able to identify and borrow the technology developed by others. Their own experiments began with a biplane glider with a wingspan of five feet. They flew this model as a kite and tested their idea that wing warping would allow them greater control than straight wings.

Once they had the basic design of the glider, they

The Wright Flyer

Wilbur and Orville Wright spent the years from 1899 to 1905 experimenting with the three basic problems of mechanical flight: lift, propulsion, and control. The Wright Flyer, a biplane flown at Kitty Hawk, North Carolina, on December 17, 1903, was the first heavier-than-air machine that solved these problems, demonstrated by sustained forward, piloted flights and landings at points at the same or higher elevation from the takeoff point.

The Flyer was constructed of ash and spruce, both light woods, and then covered by muslin. An important feature of the wing covering was that the framework could move slightly within the pockets of the muslin. The overall effect was that the structure of the plane was flexible and strong. The shape of the wings helped to provide the lift needed for the plane to get off the ground.

Propulsion, or thrust, is necessary to provide forward movement to an airplane. The Wrights' source of thrust was a device consisting of twin propellers attached to a hub, in turn attached to a four-cylinder, twelve-horsepower engine using a sprocket chain drive—technology the Wrights learned from their work with bicycles. The propulsion device was designed to be lightweight as well as reliable and strong. The engine turned the chain, which turned the wings at a high rate of speed, drawing air through them and moving the aircraft forward.

The Wrights correctly understood that control was the most important element of flight necessary for a practical machine. There are three axes around which an airplane moves. Pitch refers to the up-and-down movement of the nose of the aircraft. Yaw refers to a side-to-side movement of the nose, while roll is the up-and-down movement of the wing tips. All three movements must be under control. The Wrights placed a rudder at the rear of the Flyer to control yaw and used wing warping to control roll. The pilot controlled the aircraft through the use of a movable cradle attached to the bottom wing and connected to the wing tips and rudder by wires. The pilot lay prone in the cradle and shifted his weight, thus moving the rudder and warping the wings. In addition, an elevator at the front of the plane could be controlled with a wooden stick by the pilot. This brought the nose up or down and controlled pitch.

While modern aircraft uses fixed rather than flexible wings, and ailerons rather than wing warping, the basic premises that guided the Wrights in their development of the 1903 Flyer still underpin modern aeronautics. Every aircraft flying the skies today is a direct descendant of the aircraft flown by Orville Wright on that windy December day on the Outer Banks of North Carolina.

knew they had to build one large enough to hold a human pilot and to find a location with specific requirements to allow them to test it. They needed a lot of wind and plenty of open space. Through correspondence with the U.S. Weather Bureau, they determined that Kitty Hawk, North Carolina, would fill their needs. Once the glider was constructed, Wilbur determined to go ahead and make arrangements for them. It was a long journey. Located on the Outer Banks of North Carolina, Kitty Hawk could only be reached by boat, since there were no bridges. Nevertheless, by the end of September, 1900, both brothers and their glider were at Kitty Hawk. They had very successful tests with the glider.

The Wrights returned to the Outer Banks in 1901 with a new and improved glider, but all in all it was a very discouraging season for them. After a near catastrophic wreck, the brothers returned to Dayton, not at all sure that they would accomplish their goal.

The Wrights vigorously analyzed their data. They built a wind tunnel to test out a variety of wing constructions. In 1902, they returned to the Outer Banks. This time, they met success as they tested the new glider. All that remained was to design an engine that could fly the plane. Their own bicycle shop mechanic Charles E. Taylor successfully accomplished this task, and by the winter of 1903 they were ready to return to Kitty Hawk. On December 17, 1903, the Wright brothers took off into history. They completed a total of four flights, the longest one covering a distance of two hundred feet at an altitude of ten feet.

In the years that followed, the Wrights were very quiet about their ongoing testing and improvements to their aircraft as they were attempting to patent their machine. They did not want others to steal their technology because they believed that there was a great future in aviation. By 1906, patent in hands, they began public demonstrations of their craft. In 1908, the Wrights quieted all scoffers when Wilbur demonstrated the improved Wright Flyer in France.

In 1909, the brothers incorporated the Wright Company, setting up an airplane manufacturing factory and a flight school in Dayton. With the first commercial flight in 1910, the Wrights demonstrated the potential of their invention.

Wilbur Wright contracted typhoid fever in 1912 and died at age forty-five. His brother grieved deeply, and within three years he sold the Wright Company. Orville's last flight was in 1918. He became a spokesperson for aviation, ultimately serving on the board of the agency that became the National Aeronautics and Space Administration (NASA). He died of a heart attack in 1948.

IMPACT

The Wright brothers did not invent the airplane by themselves. They built on the work of other aviation pioneers, who sometimes even sacrificed their lives to further the study of human flight. The Wrights were, however, the first experimenters to approach the study of flight in such a systematic way. Through rigorous testing and endless attention to detail, the Wrights were the first of the early aviators to define the essential problems of flight.

The Wright brothers correctly identified control as the key problem to solve, and they did so. Since 1903, aeronautics has continued to build on their painstaking tests with their Dayton wind tunnel and their Kitty Hawk flights. In addition, the Wright brothers understood even in 1903 that machine-powered flight was not just some curiosity but rather the wave of the future. They knew that once developed, flying machines would change the course of civilization. Their vision made possible the first steps of aviation history. It is fitting that Neil Armstrong, the first astronaut to step on the Moon, carried with him a piece of the fabric from the 1903 Wright Flyer.

—*Diane Andrews Henningfeld*

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See also: ʿAbbas ibn Firnas; George Cayley; Glenn H. Curtiss; Robert H. Goddard; Charles F. Kettering; Samuel Pierpont Langley; Leonardo da Vinci; Joseph-Michel and Jacques-Étienne Montgolfier; Charles E. Taylor; Andrei Nikolayevich Tupolev; Ferdinand von Zeppelin.

ROSALYN YALOW

American medical physicist

Yalow won the Nobel Prize in Physiology or Medicine in 1977 for the discovery of the radioimmunoassay (RIA) method for detecting small concentrations of compounds, especially hormones, in body fluids. RIA allowed scientists to study the action of hormones and other compounds in the body.

Born: July 19, 1921; Bronx, New York
Also known as: Rosalyn Sussman Yalow (full name); Rosalyn Sussman (birth name)
Primary field: Physics
Primary invention: Radioimmunoassay technique

EARLY LIFE

Rosalyn Sussman Yalow (YAH-loh) was born in New York City to Simon and Clara Sussman, a Jewish couple with little formal education but who had a thirst for knowledge. Clara had only a sixth-grade education but read every book that her children brought home from school. Simon had completed only the eighth grade, but he too read avidly. He owned a twine and paper business. Rosalyn had a brother, Alexander, who was five years her senior. Learning to read at an early age, Rosalyn became a member of the local library on the day she turned five. Alexander was responsible for supervising the weekly trip to the library to turn in the last week's books and get new ones. By the eighth grade, Rosalyn had become enthralled with mathematics. She graduated from high school at age fifteen by skipping grades, and in 1937 she entered Hunter College to study chemistry.

Rosalyn Yalow. (©The Nobel Foundation)

The chemistry classes were large, and Yalow received little attention from the instructors. The smaller Physics Department had instructors who showed an interest in Yalow and encouraged her. In January, 1941, she graduated magna cum laude with the first physics degree issued to a woman from the newly established department. Although she strongly desired to go to graduate school, Yalow was told that no school would accept a Jewish girl as a physics student; therefore, she made plans to work as secretary to a professor who would allow her to take physics classes. The military draft had so depleted the number of people wanting to do graduate work that the University of Illinois College of Engineering accepted her. She was the only woman in her class of four hundred. By January, 1945, she had earned her Ph.D. in nuclear physics and had met and married her husband, Aaron Yalow. She then returned to New York to teach at Hunter College. She took on the responsibility of establishing the radioisotope laboratory at the Bronx Veterans Administration Hospital because she missed research and teaching did not occupy enough of her time.

LIFE'S WORK

At the Bronx Veterans Administration Hospital, Yalow turned a janitor's closet into a radioisotope lab and began to work with doctors in treatment and research. In two years, eight publications had resulted from her work with other physicians. In January, 1950, she resigned from teaching at Hunter College. At this time, Yalow realized that she needed someone with more medical background than she possessed, so she developed a working relationship with an internist, Dr. Solomon Berson, in the spring of that year. The pair worked closely together for the next twenty-two years, until Berson's untimely death on April

11, 1972. He taught her medicine, and she taught him physics and mathematics. They worked so closely that they could anticipate each other's thoughts. They also worked at a feverish pace, often through the night.

Yalow wanted to be not only a superb researcher and wife but also an excellent mother. In 1952, at age thirty-one, she had a son, Benjamin. Her daughter, Elanna, was born in 1954. The rules at the Bronx Veterans Administration Hospital required that women leave at the end of their fifth month of pregnancy, but Yalow had become so important to the hospital that no one told her she had to quit. On weekends, when Yalow took care of the lab animals, she took her children with her to work. Even with her exhaustive work schedule, Yalow kept up with her children's activities. Both Benjamin and Elanna attended public schools and would go on to earn their doctorates.

At the lab, Yalow and Berson began working with radioisotopes to measure the body's volume of blood, then the size of each body compartment. Using radioactive iodine 131, they studied thyroid physiology. A study using albumin labeled with a radioactive isotope led to knowledge of the rate of production of body albumin and other serum proteins. A study of insulin degradation led to the discovery that type II (adult-onset) diabetes is caused not by a lack of insulin production but by the inefficient use of insulin by the body. They also found that even a small protein such as insulin would cause an antigen to form. An antigen is any substance (such as bacteria or another foreign substance) that provokes the body's immune response. To facilitate the analysis of samples, Yalow and Berson combined chromatography and electrophoresis. Their method allowed samples to be analyzed in a half hour instead of overnight.

In a 1956 research paper, Yalow and Berson described a new method of analysis using radioisotopes to measure the concentration of an organic compound. It required three years of work to refine the idea into a practical test. This method, called radioimmunoassay (RIA), meant that compounds could be detected using a drop, instead of a cup, of blood. RIA was not quickly accepted by the scientific community, but Yalow and Berson continued to do outstanding research using the method and also began to train others to use the method. They did not patent the idea, instead sharing with the medical community what they considered to be a valuable technique to study the body.

By 1970, RIA had become a successful, standard laboratory technique. When Berson died, Yalow was devastated, but she pushed forward. Her already large number of work hours increased, and in four years her lab produced sixty papers. In 1977, she was awarded the Nobel Prize in Physiology or Medicine. Yalow retired from the Bronx Veterans Administration Hospital in 1991.

Those who knew Yalow agree that she was a very determined medical physicist. In her lab, she was often terse with colleagues. At meetings, she was known to be critical of substandard research but fiercely protective of the people who worked for her. Many have been put off by her aggressive, less-than-tactful manner. However, according to her admirers, she had no time for niceties because there was research to be done.

THE RADIOIMMUNOASSAY

Radioimmunoassay (RIA) is a method to test for antigens, which are compounds that enter the body and cause it to produce antibodies during the body's immune response. The RIA method is extremely sensitive, and it is also specific for each antigen. The procedure uses known amounts of a radioisotope-labeled antigen (antigen made radioactive) mixed with a known amount of the antibody to that antigen. The two types of molecules—antigen and antibody—bind to each other.

Next, a blood sample from a patient containing an unknown amount of "cold" (not radiolabeled) antigen is added to the mixture. As more of the patient's sample is added, the cold antigen displaces the bound radiolabeled antigen, leaving the radiolabeled antigen free. Ultimately the bound antigen-antibody is separated from the unbound radiolabeled antigen, and the radioactivity of the unbound antigen can be measured and compared to a standard "binding curve." The final result tells the researcher exactly how much antigen, and of what specific type, is present in the patient's blood serum.

RIA testing has some disadvantages: Although very specific and requiring very small blood samples, it is nevertheless expensive, requiring sophisticated equipment and special precautions to protect against radioactivity. Today, another technique for identifying antigens—known as enzyme-linked immunosorbent assay (ELISA)—has largely supplanted the RIA method. Unlike RIA, ELISA does not use radioisotopes.

IMPACT

Radioimmunoassay has changed the way that research on body systems is done. Before RIA, many of the body's compounds were present in too small a concentration to be detected. The RIA procedure allowed scientists to study hormones in the blood. Medical uses for RIA have included studies on high blood pressure, infertility, nutrition, human growth hormone, infectious diseases, cancer, vitamins, and enzymes. The list of compounds that can be tested with RIA is almost as long as the list of compounds in the body. This noninvasive procedure can detect a billionth of a gram. No radiation touches the patient; the test is done on a small amount of blood (one drop) drawn from the patient. With RIA, a pediatrician can take a drop of blood from a newborn and detect problems at a very early point in the infant's development; blood banks can scan the blood supply for different diseases; and forensic scientists can analyze drugs and poisons.

—*C. Alton Hassell*

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See also: Charles Richard Drew; Helen M. Free.

FERDINAND VON ZEPPELIN

German aircraft designer

The fund-raiser and driving visionary behind building giant rigid balloon airships, Zeppelin built a craft that flew three years before the Wright brothers' airplane. Problems of safety and maintenance made Zeppelin's airships unsuccessful, however, though his legacy remains in blimps and novelty aircraft.

Born: July 8, 1838; Konstanz, Baden (now in Germany)
Died: March 8, 1917; Charlottenburg, Germany
Also known as: Ferdinand Adolf August Heinrich von Zeppelin (full name); Count Zeppelin
Primary fields: Aeronautics and aerospace technology; military technology and weaponry
Primary invention: Rigid airship (dirigible)

EARLY LIFE

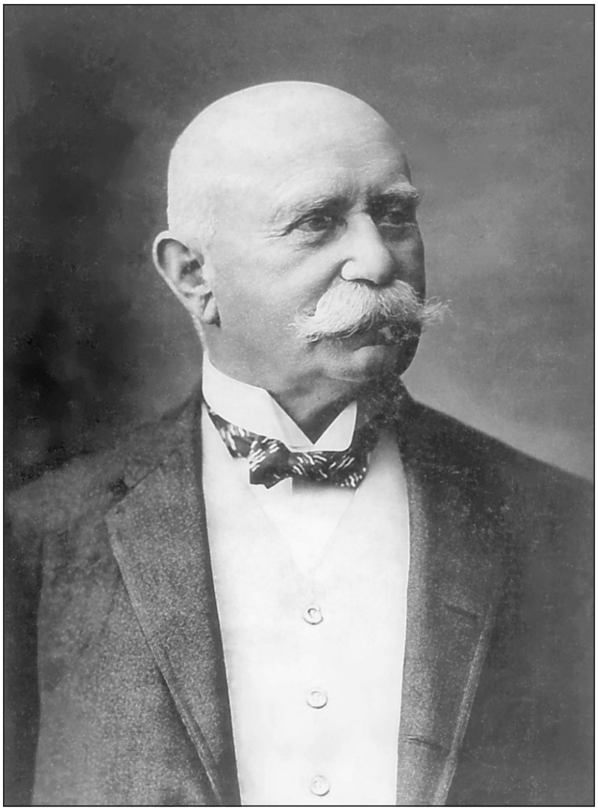
Ferdinand Adolf August Heinrich von Zeppelin (ZEHP-uh-lihn) was born near the Swiss border on Lake Constance (Bodensee in German). His father was councilor to the duke of Hohenzollern-Sigmaringen and his mother was from a family of wealthy textile manufacturers. Given an excellent private education and having an adventurous disposition, Zeppelin decided on a military career. He graduated from Ludwigsburg Military Academy and joined the Württemberg army in 1857. In 1863, he was given permission by Abraham Lincoln to observe the Civil War from Union lines, where he witnessed tethered observation balloons in army service. A short time later, he went on an adventure seeking the headwaters of the Mississippi River in Minnesota. While there, he took his first balloon flight.

Zeppelin fought in the Austro-Prussian War in 1866, which established Prussian military dominance over German-speaking Europe. In 1869, he married the Livonian baroness Isabella von Wolff and had a daughter—their only child. During the Franco-Prussian War in 1870, Zeppelin served in the cavalry and became famous for a nasty skirmish at Schirlenhof Inn, in which he was the only German not killed or captured. Later in the war, Prussia besieged Paris, and the French used balloons to communicate with the outside world. Zeppelin read of this in 1874 and was struck by the potential of steerable balloons for military and commercial use. In 1885, he was appointed military attaché for Württemberg in Berlin—the wrong man for the job. Zeppelin was not happy with Prussian domination of the German army and made enemies on the general staff. He was forced into retirement in 1891 as a brigadier general. He decided to build a practical balloon airship to fulfill his vision of the future, and to safeguard Germany from being overtaken technologically by the French. Zeppelin was not an engineer, however, and was totally reliant upon those he hired.

LIFE'S WORK

By the late nineteenth century, airships (*Luftschiffe*) as symbols of the coming age fired people's imaginations. European nations of the day were competing for military and economic dominance. Balloon aviators became romantic and patriotic figures, their achievements synonymous with national pride and the arms race. Three balloon types were experimented with: nonrigid, semirigid, and rigid. Rigid types had a girder framework that formed the aerodynamics necessary for steering.

The French successfully flew the nonrigid airship *La France* in 1884 and captured world attention. In 1887,



Ferdinand von Zeppelin. (Library of Congress)

Zeppelin wrote the king of Württemberg about the need to match this technology. By 1891, when the count was forced into retirement, he believed it was his patriotic duty to safeguard Germany by developing the airship. He hired engineers to draw up blueprints. In time, his most famous assistant would be Dr. Hugo Eckener.

In 1894, Zeppelin's requests for government development funds were rejected for poor design and planning, but he nevertheless patented his blueprints. In 1898, he sought capital to build a dirigible himself. He erected a huge shed floating on pontoons on Lake Constance. His prototype LZ1 was 39 feet in diameter and 420 feet long, with two passenger gondolas, each with two propellers run by gasoline engines. A stability weight dangled beneath, and there were top and bottom rear rudders. On the evening of July 2, 1900, when winds were mild, the LZ1 flew for twenty minutes. An engine crankshaft bent the airframe, but the ship landed safely. The LZ1 flew twice more before Zeppelin ran out of money and closed operations, in 1901. In 1902, he found no backers, although many were sympathetic. They saw Zeppelin's airships as contraptions and Zeppelin as an old hero with a harebrained idea, a bittersweet Don Quixote.

After Wilbur and Orville Wright's historic flights in December, 1903, at Kitty Hawk, North Carolina, public interest in airships increased. Zeppelin ran a lottery and mortgaged his wife's estate to fund the LZ2, which flew in early 1906. Compared to the LZ1, the LZ2 had more powerful engines and sliding midsection weights to control trim. Its engines stalled, however, and when it landed, winds blew it to pieces. That same year, Kaiser Wilhelm II founded the Society for the Study of Powered Flight to close the airship gap with France. Zeppelin raised funds to build the LZ3, which flew more than thirty miles per hour in October, 1906. It had tail and rudder improvements copied from the French, making it stable enough to discard midsection weights. Zeppelin's daughter and the crown prince were passengers in the airship. The airship once stayed aloft for eight hours. Following the success of the LZ3, the German government allocated funds and ran a lottery to build the LZ4. Meanwhile, the French airship *Patrie* carried Premier

The Dirigible

The word "dirigible" means "able to be steered." Zeppelins were dirigibles constructed of tough fabric stretched over a hollow frame (either wood or metal), into which lighter-than-air hydrogen was pumped under pressure. Steam was the common power source of the day to turn propellers, butit was impractical for balloons. Electric engines were available but underpowered and unreliable. Zeppelins used German-made gasoline engines. Zeppelin fabric was treated with flammable "dope," making it airtight. Aluminum was added to its outside to reflect heat so that the gas would not expand. Although hydrogen was quite combustible, it was available in quantity through the "water-gas shift method" of production: blowing steam through a bed of hot, glowing coke, then siphoning off the rising gas. Hydrogen was held in separate balloon compartments that resembled segments of an orange—but with a long, hollow area inside. If cells leaked or were ruptured, the ship remained aloft from the buoyancy of other cells. In later models, the hollow interior was crisscrossed with catwalks, ladders, and trapdoors to the outside. On top of the zeppelin was a valve permitting leaked hydrogen to vent into the atmosphere rather than build up inside the combustible cloth.

Helium was a better choice than hydrogen as a lifting agent: Although not quite as buoyant, it does not burn. However, helium was a laboratory curiosity until 1917, when American scientists discovered how to extract it from natural gas wells in the United States and Canada. Texas became the main source for it, and the United States held a monopoly on it for two decades, refusing to sell it to the Germans. Consequently, all zeppelins were filled with explosive hydrogen even into the late 1930's.

To further the civilian use of his dirigibles, Ferdinand von Zeppelin founded the German Airship Transportation Company (DELAG) in 1909, the first commercial airline in history. It folded when World War I began. In 1919, Hugo Eckener saved the company from ruin by restarting DELAG. He had only the LZ120, which flew successful passenger service until it was seized by Italy as war reparations in 1921. France seized Zeppelin's newly built LZ114 and LZ121. The U.S. Navy then gave Zeppelin's company a contract to build a U.S. dirigible to be named *Los Angeles*. In 1924, Eckener personally flew it across the Atlantic to the United States, where its hydrogen was pumped out and replaced with helium. The Goodyear company later entered into a partnership with Zeppelin to build airships for the U.S. Navy. The *Akron* (1931) and the *Macon* (1933) were built in Germany and helium-filled in the United States, but both wrecked within two years of their construction as a result of weather.

Georges Clemenceau over the Eiffel Tower in July, 1907. German unease increased over French airship technology.

The LZ4 was 146 feet long, had more powerful engines and larger rudders than its predecessor, and had a fuel-storage cabin halfway between two gondolas. In July, 1908, it flew for twelve hours, crossing into Switzerland and back. The king and queen of Württemberg flew in it over Lake Constance. In August, 1908, the airship force-landed in the German village of Echterdingen, where a crowd gathered around it and spontaneously sang the national anthem. Later, a storm destroyed it by dragging it into trees. Germans sent Zeppelin money to build the LZ5, and there were now government funds as well. Zeppelin became a national hero for ignoring public opinion and Prussian indifference to build his invention for Germany. In 1909, the LZ5 flew to Berlin, where it was greeted by the German emperor.

That same year, Louis Blériot flew across the English Channel in an airplane, but Germans loved "zeppelins" too much to be mindful of Blériot's feat. During 1910-1911, four zeppelins were destroyed on the ground by winds. The German general staff realized that zeppelins were vulnerable but nevertheless ordered seventeen of them in 1912 because of rumors of a French airship fleet. By World War I, in 1914, Germany had twelve airships and twenty-six airfields, and the Zeppelin works had a rival: The Schütte-Lanz Company had begun building dirigibles for government and civilian use in 1909, although all rigid balloons of the day were commonly referred to as zeppelins.

Airship bombing raids of Great Britain and France commenced in 1915. At first, there was shock and fear in the populace, but in time people got used to them. By 1916, the Allies were shooting zeppelins down with incendiary bullets and antiaircraft fire. In response, zeppelins flew above the clouds to be out of range. This necessitated lowering an observer in a cable car (*Spähkorb*) below cloud level to telephone when a zeppelin was over its target. By 1917, zeppelins had a range of almost 7,500 miles and had antifreeze coolants and oxygen masks for high altitudes. However, they were regularly shot down or crashed before they reached their objectives. The German military flew 111 *Luftschiffe* raids, dropped 311,500 pounds of bombs, killed more than 500 people, but had a loss rate of about 70 percent from combat and accidents. During the war, Zeppelin advocated all-out aerial bombing of Allied cities in order to bring victory. He died of pneumonia in Berlin on March 8, 1917, at age seventy-nine.

IMPACT

Military zeppelins never fulfilled their promise. They were equivalent to the megacannon "Big Bertha"—a terror weapon inconsequential to victory. Zeppelin raids made populations angry rather than frightened. After the initial fear of them subsided, city dwellers actually sat on park benches to watch for Zeppelins caught in Allied searchlights. In his own country, Zeppelin became a national icon—an old cavalry hero from 1870 with the spirit of a young aeronaut. He was photogenic in his visored cap and white handlebar moustache, smiling for the camera or looking determinedly off into the distance. He appeared on postcards and stamps, was quoted in newspapers, was drawn in political cartoons, and decorated by the emperor. Average Germans were so zeppelin-mad for a time that they overlooked disastrous smashups and crashes that claimed lives and cost money. When world war came in 1914, the dirigible's effectiveness was less than the danger and manpower required to fly and maintain it. Preoccupied as Germans were with great airships, it was perhaps no accident that the best early German warplanes were designed by a non-German: Antony Fokker from the Netherlands.

After the war, Germany's dirigibles were taken as war reparations. Interest in commercial flights rekindled in the 1920's. By far the most successful zeppelin was the *Graf Zeppelin*—built and piloted by Hugo Eckener and named after his former boss. It flew commercially across the Atlantic with passengers, and in 1929, around the world. There followed a brief golden age of zeppelin transatlantic flights. The United States built the *Shenandoah* (crashed in Ohio in 1925, killing fourteen), the *Akron* (crashed into the Atlantic in 1933, killing seventy-three), and the *Macon* (crashed into the Pacific in 1935, killing two). The British effort ended with the crash of the R101 (crashed in France in 1930, killing forty-eight). The spectacular filmed explosion of the *Hindenburg* (killing thirty-six) in Lakehurst, New Jersey, in 1937 was the death blow for zeppelins.

—*Jim Pauff*

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See also: Louis-Sébastien Lenormand; Joseph-Michel and Jacques-Étienne Montgolfier; Igor Sikorsky; Wilbur and Orville Wright.

Richard Zsigmondy

Austrian German chemist

Zsigmondy did much of the early work to explain and characterize colloids, mixtures in which particles of a substance are dispersed throughout another. He developed the ultramicroscope as a tool to study colloids.

Born: April 1, 1865; Vienna, Austrian Empire (now in Austria)
Died: September 24, 1929; Göttingen, Germany
Also known as: Richard Adolf Zsigmondy (full name)
Primary field: Chemistry
Primary invention: Ultramicroscope

Early Life

Richard Adolf Zsigmondy (ZHIHG-mawn-dee) was the fourth child born to Adolf Zsigmondy and Irma von Szakmary. Adolf was a well-respected, innovative dentist and head of Vienna General Hospital's surgical department. Adolf died when Richard was fifteen years old. Richard went to Vienna's public school in the Josefstadt District, receiving his secondary school degree in 1883. He then began studies at the Vienna Institute of Technology. In 1885, he published a paper with one of his teachers, Rudolf Benedict, on the detection of glycerin. In 1887, he moved to the Technical University of Munich to study organic chemistry. His dissertation, on the synthesis of indene derivatives, was accepted, and he received his Ph.D. from the University of Erlangen in 1889.

At about the same time, Zsigmondy published some of his first papers on the coloring of glass, a subject that would be important to him for his entire career. This research involved silver salts and silver particles, which caused the coloring of the glass and which could be recovered by using hydrofluoric acid to dissolve the glass. In 1891 and 1892, Zsigmondy was an assistant to physicist August Kundt. During this time, Zsigmondy researched the diathermaneity (the property of transmitting radiant heat) of glasses and ferrous salts. His research in this area brought him into contact with Otto Schott, whose laboratory in Jena was doing research in glasses. Zsigmondy and Schott would later collaborate, studying the thermal transmittance of different glasses and producing a glass that would not transmit heat rays.

Life's Work

In 1893, Zsigmondy became a teaching assistant at the Graz University of Technology. That summer, he presented a colloquium and lecture that were praised by the professors at the school and earned him a teaching qualification (habilitation). Zsigmondy taught at Graz from 1893 to 1897. He was an outstanding lecturer, and during this time he began his in-depth study of colloids. His first study was a glass dye generated by gold particles, known as "purple of Cassius" (named for its discoverer, the seventeenth century alchemist Andreas Cassius). At that time, there were two views on the nature of purple of Cassius: One stated that it was a chemical compound, a view held by the prominent Swedish chemist Jöns Jakob Berzelius; the other held that it was a "mixture of finely divided gold and stannic acid." Zsigmondy's experiments determined that the latter view was correct.

In October of 1897, Schott offered Zsigmondy a position at the Schott Glass Manufacturing Company in Jena. Zsigmondy worked there until 1900 and had many outstanding accomplishments in both the study of colloids and the practical application of the knowledge in the coloring of glasses. His Jena milk glass and his work with colored and turbid glasses earned Zsigmondy a sterling reputation. When he left Schott's company, he became a private researcher in Jena.

In 1903, Zsigmondy built and introduced the ultramicroscope to study particles smaller than could be seen in a regular microscope. The ultramicroscope was a result of collaboration with H. F. W. Siedentopf, a physicist with the Zeiss Company of Jena. In June of that year, Zsigmondy married Laura Luise Müller, with whom he had two daughters, Annemarie and Käthe. Zsigmondy introduced the immersion ultramicroscope, an improvement to the original ultramicroscope, ten years later. During his time in Jena, he wrote two noteworthy overviews of colloids. In 1907, he was offered an associate professorship at the University of Göttingen. In 1908, he was named director of the Institute of Inorganic Chemistry, a position he held until his retirement in 1929, and became a full professor in 1919. For several years after World War I, inflation was so bad that the institute ran short of the necessary materials for top-quality research.

Zsigmondy was awarded the 1925 Nobel Prize in Chemistry "for his demonstration of the heterogenous nature of colloid solutions and for the methods he used." When he won his Nobel Prize, he stated the work that he did at Graz was the beginning of his knowledge of colloids. He was searching for glass dyes, and his experimental results could not be explained by the current knowledge of chemistry.

Thomas Graham (1805-1869) had been the first to differentiate between crystalloid and colloid solutions. He observed that crystalloid solutions quickly diffused through parchment paper, leaving no residue, whereas colloid solutions such as gelatin hardly diffused through the membrane. Zsigmondy found that sometimes the same substance formed a colloid solution under one set of conditions and a crystalloid solution under a different set of conditions.

Zsigmondy was interested in making colored glass and ceramics of a consistent color. Some of his work in glass involved making a glass, noting its color, dissolving it in hydrofluoric acid, and measuring the amount of particles in the glass. Using his ultramicroscope, he was able to detect particles in the colloid solutions that were not visible with a regular microscope. He determined that the difference in the two types of solutions was the particle size of the molecules, which were larger in colloid solutions. Thus, he confirmed that colloid solutions were not homogeneous.

Zsigmondy discovered that different size particles of the same material produced different colors in glass. Using the ultramicroscope, he was able to calculate the size of the particles by counting the number of particles in a volume. For particles that were too small to see with the ultramicroscope, Zsigmondy invented the nucleus method, which was first applied to gold particles. The colloid particles were placed in a reducing solution in which metal was precipitated; the precipitating metal then settled on the colloid particles until they could be seen in the ultramicroscope. With this process, gold colloidal particles as small as one ten-millionth of a millimeter were visible in sunlight. The study of different size particles led Zsigmondy to develop a theory of coagulation, the formation of colloids by small particles aggregating together. He measured the speed of coagulation and the final size of a particle, among other variables.

Richard Zsigmondy. (©The Nobel Foundation)

During his time in Göttingen, Zsigmondy developed membrane filters with Wilhelm Bachmann. In 1922, the ultrafine filter was developed as an improvement to the membrane filters. Zsigmondy also worked on different types of colloidal solutions, including silicic acids and soap gels. His work with gold sols helped him to develop his theory of coagulation. Zsigmondy published a textbook about colloids, *Lehrbuch der Kolloidchemie* (1912), which was revised several times, and reviewers praised his writings for their clear explanations. Zsigmondy taught at Göttingen until 1929, retiring because of acute arteriosclerosis. He died a few months later.

IMPACT

Zsigmondy led in the study of colloids and their uses. He conclusively demonstrated that colloids are not the homogeneous solutions that they were thought to be. He also helped explain why some colloidal solutions do not have the same properties of others: The particles are coagulated instead of behaving as individual particles. Zsigmondy developed the methods to study colloids, such as ultramicroscopy and the nuclear method.

Colloids are prevalent in the world. They can occur in gaseous, liquid, or solid states. Colloid particles are larger—a micrometer to a nanometer in diameter—than most individual molecules. Examples of colloids are fog, whipped cream, mayonnaise, marshmallows, Jello, jellies, detergents in water, starch, proteins, water glass, glue, albumin, and rubber. Depending on the colloid particle and the state of the solution, colloid solutions may be called aerosol, foam, emulsion, sol, gel, or colloidal solid. Zsigmondy's research has been especially beneficial in fields of biochemistry and bacteriology.

—*C. Alton Hassell*

THE ULTRAMICROSCOPE

In the early twentieth century, Richard Zsigmondy and H. F. W. Siedentopf were investigating the Tyndall effect, the visible scattering of light by colloidal particles. An example of this is headlights shining through fog. Someone from the side can see the light beams because the light is reflected off the fog particles. Zsigmondy utilized this effect in his ultramicroscope, which was built in 1903.

A normal microscope does not make very small particles visible. Zsigmondy and Siedentopf decided that there were two criteria for making tiny particles visible. First, the light source needed to be the most intense possible but directed such that no light from the light source was seen by the observer. If the observer could see the light, he or she would not be able to see the light reflected off the particles. It would be like trying to see stars in the daylight. Second, the field of view needed to be as dark as possible so that the light reflected off the particles would be visible.

To produce the light source, rays from the Sun are reflected through an iris diaphragm into a dark room and onto a lens that is focused onto a slit. The light goes through the slit and through another iris diaphragm, an objective lens, and a condensing lens to be projected onto the material in the view of the microscope. The light comes from the side of the microscope, and any excess light is carefully blocked from the observer's view. For solids, a table was devised so that the sample could be moved in small steps across the view of the microscope. For liquid samples, a quartz viewing tube was attached in the view of the microscope. The viewing tube was attached to a funnel and to a drain tube. Liquid samples could be viewed and drained, the viewing tube washed out, and a new sample put into place without removing the viewing tube.

For some samples, the light needed to be polarized. A polarizer could be placed between the slit and the iris diaphragm. For an immersion sample, a plate to block the bottom part of the light would be placed between the iris diaphragm and the last objective lens.

The ultramicroscope allowed particles as small as 4 nanometers to be visible on bright, sunny days. The limit of visibility of particles was about 15 nanometers when using artificial light.

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See also: John Tyndall.

KONRAD ZUSE

German computer engineer

Zuse designed and built early computers, including the Z3, the world's first general-purpose, program-controlled, reliable computer. He also wrote the first book about digital physics.

Born: June 22, 1910; Berlin, Germany
Died: December 18, 1995; Hünfeld, Germany
Primary fields: Computer science; physics
Primary invention: Z3 programmable computer

EARLY LIFE

Born in Berlin, Germany, to Emil and Maria Zuse, Konrad Zuse (KAHN-raht TSEW-zuh) showed high intelligence as a boy. Much later, he wrote that he thought visually and therefore showed little interest in music and in the once popular hobby of building radios. He did, however, exercise a genuine talent in drawing and painting.

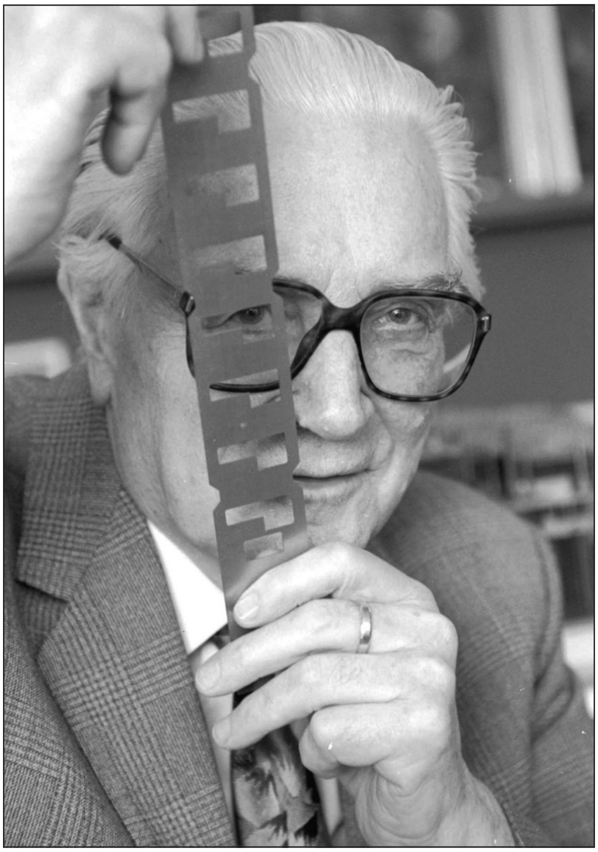
Soon after he passed an examination in 1928, Zuse enrolled in the Technische Hochschule in Berlin-Charlottenburg, where he finally majored in civil engineering. Meanwhile, besides participating in stage plays, he kept active intellectually in ways beyond what his formal studies strictly required. He designed, for instance, a futuristic city, and he gave serious thought to self-replicating machinery in outer space.

In addition, Zuse thought about how he could avoid the tedium and risk of error in the calculations that engineering required. His experience had taught him that a burdensome task in big calculations was recording intermediate answers correctly and later using them appropriately. Whether he worked with a mechanical adding machine or a slide rule, he still faced that task. To handle intermediate answers with less trouble, Zuse printed boxes on paper. Numbers in boxes together in a horizontal row would be multiplied together, and numbers in boxes together in a vertical column would be added together. The idea of the printed boxes led Zuse to his idea that he could use the patterns indicated on the paper forms to join mechanical calculators to solve complex problems. From that idea, he realized by 1934 that a machine that could calculate automatically needed only three main parts: one each for arithmetic, memory, and control.

Receiving his university degree in 1935, Zuse began work as a structural engineer for the Henschel aircraft company but soon, to his parents' dismay, quit to concentrate on building a computer. As his workplace, he chose his parents' Berlin apartment, especially the living room, and received financial help from his family and several of his friends.

LIFE'S WORK

Working at home with friends as his assistants, Zuse planned and constructed several computers that he designated by the letter *V* and by a numeral to indicate the particular model. His first computer was therefore the V1, for *Versuchsmodell* 1 (experimental model 1). It was not until after World War II that he replaced the *V* in each of his model names with a *Z*, to avoid confusion with the famous V-1 and V-2 rockets, which were *Vergeltungswaffen* (retaliatory weapons). From the time of the



Konrad Zuse holds an original part of his Z1 computer. Zuse built the first general-purpose, programmable computer in 1941, the Z3, but it was destroyed by Allied bombing raids during World War II. (AP/Wide World Photos) change of designating letters, Zuse usually referred to his early computers by using a *Z*.

Not being an expert on the mechanical calculators of the 1930's, Zuse relied on his own thinking for the Z1 and thus decided not on the commonly used decimal system, with wheels of ten positions each, but on a binary system (in which there are only two digits, 0 and 1). In 1936, when Zuse applied for a patent in Germany, he was also unfamiliar with the work of Charles Babbage, the nineteenth century British pioneer in computer science, and with the monumental paper "On Computable Numbers," which the British mathematician Alan Mathison Turing submitted that year for publication.

Actually finished in 1938, the Z1 was almost all mechanical. It worked, but not well. The trouble lay in the two arithmetic units, the one for the 16-bit significand and the other for the 7-bit exponent. As Zuse realized, the complexity of the arrangement of gears and levers needed for transmitting signals led to failures. Knowing that, in contrast, electric wires could easily carry signals around corners, Zuse started planning the Z2 before he and his coworkers had finished the Z1.

Although his friend Helmut Schreyer actually built a model section of the Z2 with vacuum tubes, Zuse intended to use electromechanical relays instead, because he could more easily visualize how they worked and because they were easier to acquire. Needing thousands of relays, Zuse, Schreyer, and others rebuilt previously used ones. In 1939, when Zuse had almost finished the Z2, the German army drafted him. He spent months as a soldier before friends managed to have him released to civilian duty. Even so, that duty was to work again for the Henschel aircraft company. Zuse had to complete the Z2 in his spare time.

The Z3 Programmable Computer

The first general-purpose, programmable computer, the Z3, like the Z1 and the Z2, used 35-millimeter film instead of punched paper tape, a keyboard with four decimal places for input that was converted to base-2 (binary), and an electric lamp for the display of output, which was converted back from base-2 to base-10 with four decimal places. In contrast to the Z1 and the Z2, however, the Z3 had electromechanical relays in the control, the arithmetic, and the memory units. In all, Konrad Zuse used about 2,600 relays in the Z3, including about 1,400 for the memory. Because he knew that sparking would wear out relays, Zuse used a metal-coated drum that revolved in contact with carbon brushes. He designed the Z3 so that the sparking would occur at the places where the brushes touched the drum but not at the relay contacts. The brushes, he realized, would wear out, but he could replace them more easily than he could the relays.

Employing the floating-point system, the binary memory could hold sixty-four words, each of which could be as long as twenty-two bits: one for the sign, fourteen for the significand, and seven for the exponent. In the arithmetic unit, Zuse used two devices that operated in parallel, one for significands and the other for exponents. Zuse designed the arithmetic unit so that it could add, subtract, multiply, divide, and determine square roots. To save calculating time, Zuse hard-wired the Z3 to solve several common problems in multiplication.

Although the Z3 was accurate to only four digits in the decimal system, its use of the floating-point system enabled it to represent huge numbers. Its speed was about that of the Harvard Mark I, designed by Howard Aiken and his team in the United States. The Z3 took between four and five seconds to multiply two numbers together and between one-fourth and one-third of a second to add numbers together.

By the standards of the twenty-first century, the Z3 was very slow and had a minuscule memory. It was, however, the first machine of its kind. Its design and construction under adverse conditions is a tribute to Konrad Zuse's unrelenting work and intellectual brilliance.

The Z2 had the same mechanical memory as the Z1, but its control and arithmetic units used relays. When Zuse finished this improved computer, he demonstrated it for the German Aeronautical Research Institute. The researchers who saw the Z2 at work realized that it was too unreliable for practical use, but they were impressed enough to offer Zuse money to pay for his work on his next computer, the Z3.

The money Zuse received did not, however, pay for conventional laboratory space, so he and his friends continued their living-room work as the Z3 took shape from 1939 until December 5, 1941, when it was finished. It worked well within its built-in limitation of a tiny memory, but that limitation led the German Aeronautical Research Institute to decide that the usual methods were better for solving the systems of linear equations on which it had planned to use the Z3. Zuse therefore had to store his computer in his parents' apartment, where Allied bombing of Berlin destroyed the machine in 1944.

Soon after he had finished the Z3, Zuse was working on the Z4, despite serving briefly again as a soldier before he was released once more to return to his official job with Henschel. During the building of the Z4, Zuse changed the location of his laboratory, but he had to endure the hardships of working in Germany when World War II had turned against his homeland. Amid wartime deprivation, on January 6, 1945, he married Gisela Brandes. Then, as the Soviets advanced toward Berlin, he and his associates laboriously moved the massive Z4 to the Experimental Aerodynamics Institute in Göttingen. It was not long, however, before Zuse had to arrange again to move the Z4, this time because of the threat of the Western Allies. Eventually, Zuse hid the Z4 in a cellar at the Bavarian village of Hinterstein, where it remained after the German surrender until Zuse and others moved it to a stable in the town of Hopferau. Yet, after Zuse cleaned and repaired the Z4, it worked just as he had thought it would, and in 1950 it found a home at the Swiss Federal Institute of Technology. At that time the only computer working on the European mainland, it now rests in the German Museum at Munich.

Meanwhile, shortly after the war's end, Zuse turned his attention to a computer language, the *Plankalkül* (plan calculus), on which he had started work in the 1930's. He finished his manuscript in 1946, but the circumstances of life in his homeland made publication difficult then. It was not until 1972 that Zuse's ideas about what he considered the initial algorithmic language reached print. Unfortunately for Zuse, by 1972 other computer languages had become so popular that few programmers used the *Plankalkül*.

Nevertheless, Zuse enjoyed success for years in postwar Europe as a founder of the computer-manufacturing company Zuse KG. Because, however, he had to spend most of his time as a businessman, not an inventor, he felt relief, along with failure, when debt led to corporate changes and he became merely a consultant after his own company in 1967 became part of Siemens AG.

With more time for his artistic and scientific passions, Zuse painted numerous pictures and, developing an idea from his youth, wrote *Rechnender Raum* (1969; calculating space), the seminal book on digital physics, in which he presented his theory that discrete laws govern the physical universe. The universe, he said, is the output of a computation on a cellular automaton; in other words, an enormous grid of cells, acting as a network of computers working in parallel, has determined everything that is or will be. Whether or not such is the case, Zuse died in Hünfeld on December 18, 1995, when he was eighty-five years old.

IMPACT

By the time he died, Zuse had received several honorary doctorates and other awards, including the Computer Pioneer Award of the Institute of Electrical and Electronics Engineers and the first Konrad Zuse Medal. Working in wartime Germany with almost no knowledge of what inventors in the United States and Great Britain were doing in his field and, for that matter, no knowledge of what work Germans beyond his team were doing, he designed and, with his associates, built the Z3, the first successful computer controlled by a program and used for general calculation. In computer science, he developed an early algorithmic language. Extending his thoughts to cosmology, he presented an idea that, while it remains unproven, has prompted discussions and stirred imaginations.

In *The Computer—My Life* (1993), Zuse implied that he did not receive the recognition he deserved as a founder of computer science and engineering. His years spent as a business executive contributed to his scientific obscurity relative to his accomplishments, as did his isolation in Germany in the years just before, during, and even just after World War II. Furthermore, his slowness in turning to electronic components put him behind a number of other pioneers. It may be true that the line of development of computers in English-speaking countries does not pass through Zuse's work on the Z3 or the *Plankalkül*, but Zuse deserves credit for what he did before anyone else had done it.

—Victor Lindsey

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See also: John Vincent Atanasoff; Charles Babbage; Clifford Berry; Ted Hoff; John Napier.

VLADIMIR ZWORYKIN

Russian American electronics engineer

Known as "the true inventor of television" (a claim sometimes disputed), Zworykin developed the iconoscope, the standard television camera until 1946, as well as the kinescope, its receiver. He also pioneered practical, noncommunication uses for the technology, such as the electron microscope.

Born: July 30, 1889; Murom, Russia
Died: July 29, 1982; Princeton, New Jersey
Also known as: Vladimir Kosma Zworykin (full name)
Primary fields: Communications; electronics and electrical engineering
Primary inventions: Iconoscope; kinescope; electron microscopy

EARLY LIFE

Vladimir Kosma Zworykin (VLA-dee-meer KOZ-mah TSVOR-ee-kihn) was born to a prosperous merchant in Murom, Russia. In 1910, he entered the St. Petersburg Institute of Technology to study with physicist Boris Rosing, who three years earlier had completed and demonstrated his first cathode-ray tube television. The young Zworykin's work in Rosing's laboratory led to an improved design that Rosing demonstrated in 1911. World War I interrupted Zworykin's research in 1914: His skill in electronics made him valuable to the Russian Signal Corps, which assigned him to detached service with Russian Marconi, evaluating communications equipment for the Russian army. When the Russian Revolution (1917) began co-opting all research, especially in such a vital industry as communications, Zworykin sought to leave his country. His exact itinerary is difficult to establish (he apparently went back to Russia at one point), but he may have spent a year in Paris studying X rays under Paul Langevin in 1918 before settling in the United States the following year. He became a U.S. citizen in 1924.

Zworykin began working for Westinghouse Electric in Pittsburgh while pursuing graduate study in physics at the University of Pittsburgh. By 1926, he had completed his Ph.D. and demonstrated a television system based on the cathode-ray tube (CRT). Westinghouse management told him to stick to more practical projects. In 1929, he successfully demonstrated his kinescope, a CRT receiver that was the basis for all picture tubes in the twentieth century. The demonstration impressed David Sarnoff of the Radio Corporation of America (RCA), who hired Zworykin for his new laboratory in Camden, New Jersey. There Zworykin developed an electronic scanner that he called an iconoscope, to deliver the image to a kinescope. It was Zworykin's basic design that the Germans used to televise the Berlin Olympics in 1936. Zworykin continued to develop applications for his iconoscope and kinescope, particularly electron microscopy, which was under development in Germany in the 1930's, until his retirement from RCA in 1954.

LIFE'S WORK

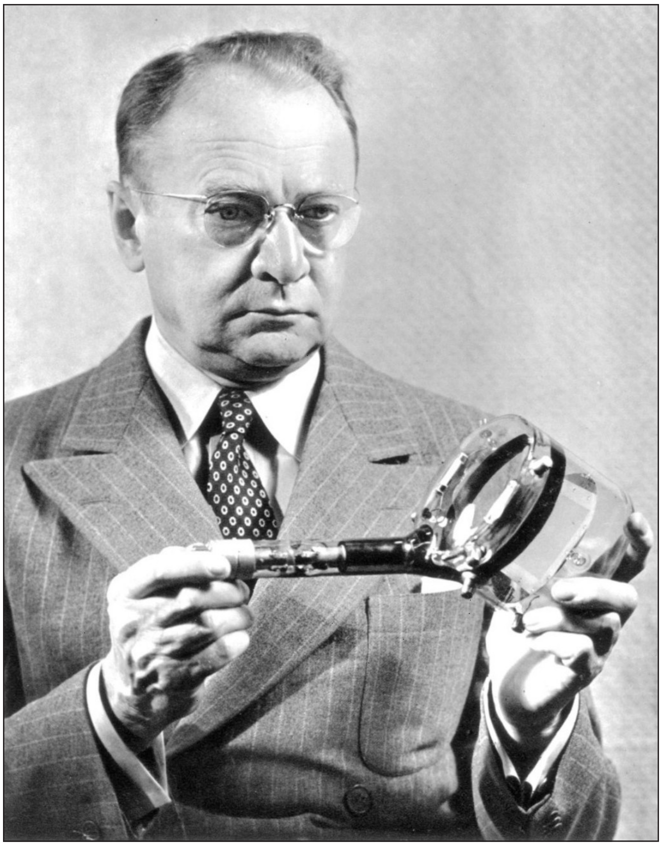
When introduced as the "father of television" in 1951, Vladimir Zworykin scorned the title. With a disparaging remark about the children's show *Howdy Doody*, he remarked that he would not want his own children to watch what the medium had become. Zworykin had expected his invention to serve science and industry, not merely entertain. His confidence in the importance of industry is ironic, since management at Westinghouse gave very little encouragement to his early experiments in television. His 1923 patent application was still pending in the fall of 1925 when he demonstrated his improvements on the design. Because the image he broadcast was still—a simple *X*—management, not understanding the technical achievement, was unimpressed and ordered him to concentrate on other projects. However, the demonstration led to a new patent application that included a key element in television camera design: the creation of a "mosaic" pattern on the image plate. Zworykin's 1923 patent had spoken of a "layer" of photoelectric material, but subsequent experiments proved the need to have discrete areas (what are now called "pixels") electrically insulated from one another.

Following the letter of Westinghouse's ban on his television research, Zworykin continued to develop hardware that could be used in television but that had other commercial applications. One success in this area was his mercury-arc light valve, which would later be the basis for his kinescope. He also produced a photoelectric cell in a vacuum tube that was a great deal more sensitive than previous cells. Westinghouse billed it as an optical smoke detector. Also, since photocells became desensitized with use, Zworykin in 1926 developed potassium-based photocells that outlasted the sodium cells then in use. While banned from direct television research, Zworykin was still free to apply for patents, and his 1928 patent for a cathode-ray television system caught the eye of one of the leaders in television research, A. A. Campbell Swinton, who convinced Westinghouse management of the viability of Zworykin's television work. Consequently, Zworykin was free to develop the kinescope, which he demonstrated in 1929.

Hired away from Westinghouse by David Sarnoff at RCA, Zworykin at last had the freedom (and funding) to pursue his television research. In 1931, he produced a working version of the iconoscope, though his success was marred by the fact that other researchers had beat him to the patent office, even though he was the first to prove "operability," a key criterion in patent disputes. In 1932, RCA demonstrated Zworykin's iconoscope in a broadcast from the Empire State Building, viewed by fifty top radio and electronics manufacturers. The Depression made Sarnoff hesitant to develop commercial applications for Zworykin's work, though he continued to support it, albeit under tight secrecy. By 1933, however, Sarnoff decided to publicize the iconoscope, and a picture of it appeared in the Sunday *New York Times* of July 2. Zworykin's scholarly paper on the iconoscope was reported by the newspaper as front-page news. The U.S. State Department allowed Zworykin at this time to return to Russia and deliver his paper to scientists there. Shortly after, and, it is likely, in no small part due to this trip, the United States and the Soviet Union resumed diplomatic relations for the first time since the 1917 revolution.

In 1936, RCA staged a second demonstration of its now-improved television system broadcast from the Empire State Building. However, there were only three receivers in the city, and the highest stated ambition was to have one hundred sets in operation in New York. The home market for receivers, announced in 1932, had not materialized. A repeat demonstration in 1937 was reported to have greater clarity, though the contrast was higher than that of film. A 1938 demonstration showed a higher percentage of gray tones. At the opening of the New York World's Fair in April of 1939, RCA began the first public television service, with Zworykin's iconoscope cameras and kinescope receivers.

In 1940, Zworykin demonstrated his improvements on the electron microscope, and he gave a scholarly paper on the subject. He also published his classic book, *Television: The Electronics of Image Transmission*, which detailed the state of the art at that time. For his work on electron microscopy, Zworykin was awarded the Rumford Medal by the American Academy of Arts and Sciences in 1941. During the war years, Zworykin was influential in the development of the infrared snoop-



Vladimir Zworykin holds his iconoscope, the first practical television camera tube. (The Granger Collection, New York)

The Iconoscope

Although Vladimir Zworykin's most indisputable claims in the invention of television—the kinescope and the iconoscope—have been disputed by zealous historians, Zworykin's version of the iconoscope was vital to the earliest television camera. His iconoscope's design elements pervade all modern video. The initial part of the iconoscope is little different from a film camera: A series of lenses focuses the image on an image plate. Instead of being chemically treated like a film plate, however, the image plate is connected to photoelectric cells. A cathode-ray tube sweeps the image on the plate with a charged beam. (The plate itself was one of Zworykin's innovations.) By baking silver dusted through a ruled screen onto a mica plate, Zworykin's team produced a four-inch-square mass of minute sections of highly conductive silver oxide—each section insulated from the others in what is now known as a "pixel." It is this part of the process that makes the iconoscope similar to Philo T. Farnsworth's image dissector, which was key to Farnsworth's battle for patent priority. The greater the intensity of light in a given pixel, the greater the charge that goes to the cells. Thus, a light image is converted to an electronic image. The electronic information is then amplified.

The advantage of Zworykin's scope over Farnsworth's image dissector (and the earlier iconoscope of Kálmán Tihanyi) was its ability to store charges, allowing the camera to be used with lower intensity studio light. Another Zworykin improvement (even over his own earlier attempts at an electronic camera) was having the cathode ray scan the same side of the plate on which the image fell, though a later patent dispute proved that Tihanyi had invented the single-sided plate. The innovation is obvious in retrospect, but engineers at the time feared that the electron gun would damage the plate. The two-sided design, however, had a host of its own problems: pinholes in the plate causing images to spot, short circuits, and insufficient insulation. Zworykin's design eliminated all three problems. From 1936 to 1946, the heart of all commercial television cameras was the Zworykin iconoscope. Even when the iconoscope was replaced in 1946 with the image orthicon tube, the latter retained the image plate with photoelectric receptors and the electron scan of Zworykin's design—though it also incorporated Farnsworth's dissector.

erscope, once being stopped by the police in Princeton, New Jersey, for driving without headlights to test the infrared "night vision" effect. Because he was driving around the RCA Laboratories, the police suspected that he was a spy.

After the war, Zworykin went to work on a large-screen color television, which he demonstrated publicly for the first time in March of 1947. By this time, he had been promoted to vice president of RCA Laboratories. By the time he retired in 1954, color television was on its way to American homes, and every camera and receiver depended at least in part on a Zworykin invention. Zworykin died on July 29, 1982, at the Princeton Medical Center, at the age of ninety-two.

Impact

Although RCA's claim for Zworykin as the "father of television" may be a bit exaggerated, Zworykin surely contributed as much as any one inventor to the development of video technology. Furthermore, his pioneer work on the electron microscope, and his wartime development of television-guided missiles, which Zworykin had proposed as early as 1934, were major contributions to the Allied war effort. During the war, Zworykin served as a member of the Ordnance Advisory Committee on Guided Missiles, and he was a scientific adviser to the commanding general of the U.S. Army Air Force. In the 1950's, the Institute of Electrical and Electronics Engineers (IEEE) named its highest award in video technology the V. K. Zworykin Award. In November of 1980, ninety-one-year-old Zworykin was awarded the Fellowship Citation Plaque of the Royal Television Society of London at the 122nd technical conference of the Society of Motion Picture and Television Engineers (SMPTE). In 1984, he received a posthumous Emmy, the Trustees Award of the National Academy of Television Arts and Sciences, for his seventy-year career in television research. Robert B. Frederick, the president of RCA, accepted the Emmy in Zworykin's honor. In addition to directing what was in the 1940's the largest broadcast laboratory in the world, Zworykin wrote six informative books on the subject of television that became standard reading.

—*John R. Holmes*

Further Reading

Abramson, Albert. *The History of Television, 1942 to 2000*. Jefferson, N.C.: McFarland, 2003. An overview of the developments in television since World War II. Helpful for placing Zworykin's accomplishments in historical perspective. Copiously illustrated with archival photographs.

_______. *Zworykin, Pioneer of Television*. Urbana: University of Illinois Press, 1995. The most thorough discussion of Zworykin's contributions to television available, this work is scrupulously documented, though unfortunately not with a separate bibliography: The researcher must scour the 292 pages of notes to find book and article titles.

Flehr, Paul D. *Inventors and Their Inventions: A California Legacy Seen Through the Eyes of a Patent Attorney*. Palo Alto, Calif.: Pacific Books, 1990. Includes a discussion of Zworykin's advances in television technology from the point of view of patent law. Not very helpful on the technical side, but offers a clearer picture than do the standard television histories of the legal issues involved.

Udelson, Joseph H. *The Great Television Race: A History of the American Television Industry, 1925-1941*. Tuscaloosa: University of Alabama Press, 1982. A readable narrative of Zworykin's race against other industry hopefuls, particularly Philo T. Farnsworth, to produce commercial television equipment. What is gained in storytelling interest, however, is lost in perpetuating futile quibbles over the various television "firsts."

Zworykin, V. K., and G. A. Morton. *Television: The Electronics of Image Transmission*. New York: John Wiley & Sons, 1940. A history of the development of video technology, in Zworykin's own words. While Zworykin is not shy about documenting his own role in developing the medium, he gives ample credit to his competitors. The descriptions are technically detailed yet understandable to the nontechnical reader.

See also: Ernst Alexanderson; Edwin H. Armstrong; Karl Ferdinand Braun; Philo T. Farnsworth.

Appendixes

History of U.S. Patent Law

A patent is an exclusive legal protection granted to inventors. It protects the intellectual property of those who create a new and useful invention against duplication by third parties for a fixed term of years. Under U.S. patent law, "invention" is a term of art broadly referring to technological, design, and aesthetic innovations or improvements. It also refers to new industrial and scientific processes as well as certain discoveries and manipulations of the natural world. However, principles of mathematical and natural science and mere ideas of any kind are not patentable. Patent law encourages and rewards the creativity of inventors with exclusive legal protection, while serving to eventually place all inventions in the public domain. Patent law has been instrumental in the growth of American business and in technological and scientific excellence. The law of patents is closely related to that of copyright and trademark. Copyright protects the creative works of authors and artists. Trademark protects the marks, brands, and insignias used by commercial enterprises to identify their products and foster good will.

The first modern patents arose in the flourishing commercial and guild culture of medieval Venice. In the fifteenth century, the Senate of Venice enacted a statute authorizing the Guild Welfare Board to grant exclusive privileges for ten years to inventors of new industrial methods. Venetian patents were granted for stoves, printing, and corn and flour mills. The idea of a patent was well known to English common law. The Crown granted monopolistic and charter privileges to merchants and traders, as a mark of favor and patronage, to raise revenue and to further English excellence and commerce in industry. In 1623, Parliament passed the Statute of Monopolies, which abolished royal prerogatives to grant monopolies but allowed for patents for terms of fourteen years for manufacturing inventions. Several of the North American colonies of Great Britain enacted their own versions of a patent law. The colony of Massachusetts enacted a loosely phrased patent statute in 1641, and the colony of Connecticut did likewise in 1672. Apparently, the first patent in the American colonies was granted to Samuel Winslow of Massachusetts in 1641 for inventing a new method of manufacturing salt for fisheries.

Federal Patent Law

After America declared independence from Great Britain, states continued to grant patents. However, the framers of the U.S. Constitution realized that the development of a national economy required the newly created federal government to possess the exclusive power to grant patents. Under Article I, section 8, clause 8 of the Constitution, Congress is given the power "to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." Congress has passed patent laws on a steady basis, some acts completely revising patent law and some representing a mere refinement of existing law. The goal of patent law is to encourage and reward imagination and industry while ensuring fair competition and the widest dissemination of the fruits of human ingenuity. Patent jurisprudence has alternated between generous awarding of patents to reward inventors and restricting the number of patents so as to increase competition and lower entry costs to business.

Given the constitutional mandate, U.S. patent law is governed by federal statutes. The first patent act was passed in 1790 in the first congressional session. This Patent Act of 1790 authorized the granting of patents to the "first inventor or discoverer" of an invention if the invention was new and determined by a board consisting of the attorney general, the secretary of war, and the secretary of state to be sufficiently significant. The first federal patent granted was to Samuel Hopkins on July 31, 1790, for a new method of making industrial potash. However, it was soon realized that the examination of patents required of the cabinet officers was a burden to their other duties. A reform patent act was passed in 1793 allowing for the secretary of state to grant patents good for fourteen years. Most important, the act eliminated the examining board and allowed for a patent to be obtained by simple registration. This merely clerical system resulted in numerous useless and even fraudulent patents. As a result, perhaps the most important patent act was passed in 1836, establishing the modern patent system. It created a United States Patent Office as a bureau of the Department of State, headed by a commissioner of patents. As with the original 1790 board, the Patent Office was obligated not only to issue patents but also to investigate the merits of the applications, determining if the discovery or invention represented a true and useful innovation.

The Patent Act of 1836 also created the patent numbering system used to this day. Finally, an appeals board was instituted to hear claims from denied applicants. In 1842, the act was amended to provide for design patents, which are patents that protect the ornamental features of manufactured items. In 1870, the act was revised to require the applicant to present a more detailed description of the invention, as well as a more explicit claim of the subject-matter protection the inventor seeks. In 1897, patent protection was barred for inventions described in a printed publication in the United States or a foreign country. The Plant Patent Act of 1930 allowed for the patenting of laboratory-derived hybrid plants that reproduce asexually.

With the Great Depression, there arose greater public and judicial hostility to patents, as constituting restraints on business competition and trade. In the 1940's, the courts began to require that a patent show more than mere novelty and usefulness. In *Cuno Engineering Corporation v. Automatic Devices Corporation* (1941), the U.S. Supreme Court suggested that a patentable invention needed to show a "flash of genius." In *Mercoid Corp. v. Mid-Continent Investment Co.* (1944), the Court broadened its strictures on the misuse of patents. In *Great Atlantic & Pacific Tea Co. v. Supermarket Equipment Corporation* (1950), the Supreme Court disfavored patents that were new combinations of old parts. The community of investors, patent lawyers, and established businesses reacted against these trends. The Patent Act of 1952 invalidated these judicial doctrines and restored a more generous view of the granting of patents. It also updated the statutory language to make explicit that patents were provided for inventions and "processes." Processes are defined as the method or steps in achieving a useful technological result. The Atomic Energy Act of 1954 excludes the patenting of any invention that chiefly pertains to nuclear material or weapons.

In line with this trend, modern law has seen a major expansion in the types of things and methods that can be patented. In 1982, Congress created the United States Court of Appeals for the Federal Circuit to hear, consolidate, and provide expertise on the increasing volume of patent cases. In 1995, the length of patent protection was changed from a term of seventeen years from the issue date to a term of twenty years from the filing date. The American Inventors Protection Act of 1999 provided for the publication of patent applications. The Patent and Trademark Office Authorization Act of 2002 broadened the appellate rights of applicants. The United States has also signed three international agreements that have shaped patent law. The 1883 Paris Convention for the Protection of Industrial Property internationalized patent rights. The 1970 Patent Cooperation Treaty simplified the process for obtaining multinational patents. The Uruguay Round Agreements Act of 1994, implementing the Agreement on Trade-Related Aspects of International Property Rights, internationalized the twenty-year patent term. Many of the recent developments in patent law concern the scope of patentable subject matter in computer programming, biotechnology, and medical treatments.

How Patents Work

A patent is a valuable economic monopoly that allows the patent holder to exclude competitors from making use of, selling, or importing an invention for a fixed period of time. The Patent Act is found in Title 35 of the U.S. Code. Under section 101 of Title 35, "any new and useful process, machine, manufacture, composition of matter, or any new and useful improvement thereof" is patentable. Abstract ideas, natural phenomena, and laws of nature are not. Three types of patents may be obtained: utility patents, for new products or processes; design patents, for new design features of manufactured products; and plant patents, for new varieties of asexually reproduced plants. Under the current patent statute, a patent expires twenty years after the filing date. To obtain a patent, the inventor must submit a detailed description of the invention or process for publication upon grant by the government. This publication both protects the inventor's intellectual property while placing the invention or process in the public domain upon the expiration of the patent.

To acquire a patent for an invention or improvement, the inventor first files an application with the Patent and Trademark Office. The process of applying for a patent is called patent prosecution; it is an often lengthy, technical, and expensive procedure. A provisional patent is a simplified process for retaining patent rights for one year before a regular patent application is filed. The patent application must contain a "specification," which refers to a written description and a claim. The written description usually includes a survey of the "prior art" that is the problem or opportunity facing the inventor, and related inventions in the field. The application also includes a summary of the invention or process and how it resolves the problem or opportunity. A detailed, technical description of the invention or process, usually accompanied by drawings or illustrations, is included. The description must be sufficient to disclose to a person skilled in the relevant field how to make and use the invention.

Thus, patent law not only encourages and rewards the inventor for his or her industry and imagination but also seeks to ensure that his or her ideas and methods are eventually open to public dissemination and competition. The claim defines the scope of the patent protection by describing what would constitute an infringement of the patent. The applicant must also sign an oath or declaration that he or she is the first inventor of the invention or improvement. Finally, the applicant must pay a filing fee.

Once a complete application is submitted, an expert examiner from the Patent Office examines the application for compliance with the requirements of the Patent Act. Under current law, to receive a patent grant, an invention must meet three requirements. First, the invention must be novel or new as compared with prior art—that is, not previously known or used in the United States or a foreign country. If the subject matter of the application has been in public use for more than a year, it is not new or novel. Second, it must be useful. To satisfy the requirement of usefulness, the invention must work as indicated and confer some utility or benefit to society. Third, it must be nonobvious—that is, not readily apparent on the basis of the prior art by a person of ordinary skill. If the patent application is judged to meet these three requirements, a patent is granted. If not, the examiner may object to the application or reject it. In response, the applicant may amend the application. If the application receives a final rejection, the applicant may file an appeal with the Patent Office Board of Appeals.

If the patent is granted, it is valid for twenty years from the date of the filing of the application. (A design patent is valid for fourteen years.) If the patent is infringed by a third party during this period, the patent holder may sue to recover money and perhaps punitive damages or enjoin the infringed use of the invention. The scope of patent rights, however, is often settled outside civil lawsuits by patent licensing contracts. Ownership rights to a patent may also be assigned to another party.

—*Howard Bromberg*

Further Reading

Durham, Alan. *Patent Law Essentials: A Concise Guide*. Westport, Conn.: Praeger, 2004. An in-depth guide to patent law, written to be understandable by lay people and sufficient for patent law professionals.

Martin, John, ed. *Patents: Issues and Legal Developments*. New York: Nova Science, 2002. Collection of scholarly essays on modern patent law and its impact on business, technological innovations, and science.

Shechter, Roger, and John Thomas. *Principles of Patent Law*. St. Paul, Minn.: Thomson West, 2004. A volume in the Concise Hornbook Series by two law school professors presents the statutes and doctrines of patent law in a succinct, straightforward manner.

CHRONOLOGICAL LIST OF ENTRIES

Personages appearing in this list are the subjects of essays in Great Lives from History: Inventors and Inventions*, and are arranged here by birth year and include year of death where applicable. Four essays have two subjects, who are listed here separately: Auguste and Louis Lumière, André and Édouard Michelin, Joseph-Michel and Jacques-Étienne Montgolfier, and Wilbur and Orville Wright.*

Ancient World to 475 C.E.

Huangdi (c. 2704 B.C.E.-c. 2600 B.C.E.)
Aristotle (384 B.C.E.-322 B.C.E.)
Ctesibius of Alexandria (c. 290 B.C.E.-probably after 250 B.C.E.)
Archimedes (c. 287 B.C.E.-212 B.C.E.)
Cai Lun (c. 50 C.E.-c. 121 C.E.)
Hero of Alexandria (Before 62 C.E.-c. 100 C.E.)
Ptolemy (c. 100 C.E.-c. 178 C.E.)

Middle Ages, 476-1400

Al-Khwārizmī (c. 780 C.E.-c. 850 C.E.)
ʿAbbas ibn Firnas (810 C.E.-887 C.E.)
Al-Jazarī (c. 1150-c. 1220)
Roger Bacon (c. 1220-c. 1292)
Johann Gutenberg (1394-1399-probably February 3, 1468)

1401-1600

Leonardo da Vinci (April 15, 1452-May 2, 1519)
Gerardus Mercator (March 5, 1518-December 2, 1594)
John Napier (1550-April 4, 1617)
Faust Vrančić (1551-January 17, 1617)
Sir John Harington (1561-November 20, 1612)
Santorio Santorio (March 26 or 29, 1561-February 22 or March 6, 1636)
Galileo (February 15, 1564-January 8, 1642)
Hans Lippershey (c. 1570-September, 1619)
Giovanni Branca (April 22, 1571 [baptized]-January 24, 1645)
Zacharias Janssen (c. 1580-c. 1638)

1601-1700

Otto von Guericke (November 20, 1602-May 11, 1686)
Evangelista Torricelli (October 15, 1608-October 25, 1647)
Blaise Pascal (June 19, 1623-August 19, 1662)
Christiaan Huygens (April 14, 1629-July 8, 1695)
Antoni van Leeuwenhoek (October 24, 1632-August 26, 1723)
Robert Hooke (July 18, 1635-March 3, 1703)
James Gregory (November, 1638-October, 1675)
Sir Isaac Newton (December 25, 1642-March 20, 1727)
Gottfried Wilhelm Leibniz (July 1, 1646-November 14, 1716)
Thomas Savery (c. 1650-May, 1715)
Bartolomeo Cristofori (May 4, 1655-January 27, 1732)
Thomas Newcomen (January or February, 1663-August 5, 1729)

Jethro Tull (March 30, 1674 [baptized]-February 21, 1741)
Abraham Darby (c. 1678-May 8, 1717)
Daniel Gabriel Fahrenheit (May 24, 1686-September 16, 1736)
Pieter van Musschenbroek (March 14, 1692-September 19, 1761)
John Harrison (March, 1693-March 24, 1776)
Ewald Georg von Kleist (June 10, 1700-December 11, 1748)

1701-1800

John Kay (July 16, 1704-1780 or 1781)
Benjamin Franklin (January 17, 1706-April 17, 1790)
Jacques de Vaucanson (February 24, 1709-November 21, 1782)
John Campbell (c. 1720-December 16, 1790)
James Hargreaves (January 8, 1720 [baptized]-April 22, 1778)
Nicolas-Joseph Cugnot (February 26, 1725-October 2, 1804)
Benjamin Banneker (November 9, 1731-October 9, 1806)
Sir Richard Arkwright (December 23, 1732-August 3, 1792)
Joseph Priestley (March 13, 1733-February 6, 1804)
Jesse Ramsden (October 6, 1735-November 5, 1800)
James Watt (January 19, 1736-August 25, 1819)
Joseph-Michel Montgolfier (August 26, 1740-June 26, 1810)
David Bushnell (August 30, 1742-1824)
John Fitch (January 21, 1743-July 2, 1798)
Thomas Jefferson (April 13, 1743-July 4, 1826)
Edmund Cartwright (April 24, 1743-October 30, 1823)
Jacques-Étienne Montgolfier (January 6, 1745-August 2, 1799)
Alessandro Volta (February 18, 1745-March 5, 1827)
John Stevens (1749-March 6, 1838)
Edward Jenner (May 17, 1749-January 26, 1823)
Benjamin Thompson (March 26, 1753-August 21, 1814)
William Murdock (August 21, 1754-November 15, 1839)
Oliver Evans (September 13, 1755-April 15, 1819)
John Loudon McAdam (September 21, 1756-November 26, 1836)
Louis-Sébastien Lenormand (1757-1837)
Nicéphore Niépce (March 7, 1765-July 5, 1833)
Robert Fulton (November 14, 1765-February 24, 1815)
Eli Whitney (December 8, 1765-January 8, 1825)
Charles Macintosh (December 29, 1766-July 25, 1843)
Richard Trevithick (April 13, 1771-April 22, 1833)
Marie Anne Victoire Boivin (April 9, 1773-May 16, 1841)
George Cayley (December 27, 1773-December 15, 1857)
Joseph-Louis Gay-Lussac (December 6, 1778-May 9, 1850)
Sir Humphry Davy (December 17, 1778-May 29, 1829)
René-Théophile-Hyacinthe Laënnec (February 17, 1781-August 13, 1826)
George Stephenson (June 9, 1781-August 12, 1848)
William Sturgeon (May 22, 1783-December 4, 1850)
Joseph von Fraunhofer (March 6, 1787-June 7, 1826)
Jacques Daguerre (November 18, 1787-July 10, 1851)
Robert Stirling (October 25, 1790-June 6, 1878)
Thomas L. Jennings (1791-February 11, 1859)
Peter Cooper (February 12, 1791-April 4, 1883)
Samuel F. B. Morse (April 27, 1791-April 2, 1872)
Michael Faraday (September 22, 1791-August 25, 1867)
Charles Babbage (December 26, 1791-October 18, 1871)
Joseph Henry (December 17, 1797-May 13, 1878)
Charles Goodyear (December 29, 1800-July 1, 1860)

1801-1900

George Biddell Airy (July 27, 1801-January 2, 1892)
Charles Wheatstone (February 6, 1802-October 19, 1875)
John Ericsson (July 31, 1803-March 8, 1889)
John Deere (February 7, 1804-May 17, 1886)
Norbert Rillieux (March 17, 1806-October 8, 1894)
William Fothergill Cooke (May 4, 1806-June 25, 1879)

John Augustus Roebling (June 12, 1806-July 22, 1869)
James Nasmyth (August 19, 1808-May 7, 1890)
Louis Braille (January 4, 1809-January 6, 1852)
Cyrus Hall McCormick (February 15, 1809-May 13, 1884)
Alexander Bain (October 10, 1810-January 2, 1877)
Robert Wilhelm Bunsen (March 31, 1811-August 16, 1899)
Sir William Robert Grove (July 11, 1811-August 1, 1896)
Elisha Graves Otis (August 3, 1811-April 8, 1861)
Isaac Merrit Singer (October 27, 1811-July 23, 1875)
Richard March Hoe (September 12, 1812-June 7, 1886)
William Bullock (1813-April 12, 1867)
Joseph Glidden (January 18, 1813-October 9, 1906)
Sir Henry Bessemer (January 19, 1813-March 15, 1898)
Samuel Colt (July 19, 1814-January 10, 1862)
Henri Nestlé (August 10, 1814-July 7, 1890)
Werner Siemens (December 13, 1816-December 6, 1892)
Richard Gatling (September 12, 1818-February 26, 1903)
Christopher Latham Sholes (February 14, 1819-February 17, 1890)
Elias Howe (July 9, 1819-October 3, 1867)
Léon Foucault (September 18, 1819-February 11, 1868)
John Tyndall (August 2, 1820-December 4, 1893)
Hermann von Helmholtz (August 31, 1821-September 8, 1894)
Étienne Lenoir (January 12, 1822-August 4, 1900)
Louis Pasteur (December 27, 1822-September 28, 1895)
Joseph Monier (November 8, 1823-March 13, 1906)
Sylvester Roper (November 24, 1823-June 1, 1896)
Lord Kelvin (June 26, 1824-December 17, 1907)
Martha J. Coston (April 10, 1828-January 12, 1904)
Joseph Wilson Swan (October 31, 1828-May 27, 1914)
Levi Strauss (February 26, 1829-September 26, 1902)
George Mortimer Pullman (March 3, 1831-October 19, 1897)
David Edward Hughes (May 16, 1831-January 22, 1900)
John Stith Pemberton (July 8, 1831-August 16, 1888)
Nikolaus August Otto (June 10, 1832-January 26, 1891)
Sir William Crookes (June 17, 1832-April 4, 1919)
Alfred Nobel (October 21, 1833-December 10, 1896)
Dimitry Ivanovich Mendeleyev (February 8, 1834-February 2, 1907)
Gottlieb Daimler (March 17, 1834-March 6, 1900)
Samuel Pierpont Langley (August 22, 1834-February 27, 1906)
Elisha Gray (August 2, 1835-January 21, 1901)
Mark Twain (November 30, 1835-April 21, 1910)
Lewis Waterman (November 20, 1837-May 1, 1901)
Margaret E. Knight (February 14, 1838-October 12, 1914)
Ferdinand von Zeppelin (July 8, 1838-March 8, 1917)
Josephine Garis Cochran (March 8, 1839-August 3, 1913)
John Boyd Dunlop (February 5, 1840-October 23, 1921)
John Philip Holland (February 29, 1840-August 12, 1914)
Carl von Linde (June 11, 1842-November 16, 1934)
Sir James Dewar (September 20, 1842-March 27, 1923)
Elijah McCoy (March 27, 1843, or May 2, 1844-October 10, 1929)
Carl Benz (November 25, 1844-April 4, 1929)
Wilhelm Conrad Röntgen (March 27, 1845-February 10, 1923)
Gabriel Lippmann (August 16, 1845-July 13, 1921)
Ira Remsen (February 10, 1846-March 4, 1927)
George Westinghouse (October 6, 1846-March 12, 1914)
Thomas Alva Edison (February 11, 1847-October 18, 1931)
Alexander Graham Bell (March 3, 1847-August 2, 1922)
Lewis Howard Latimer (September 4, 1848-December 11, 1928)
James Murray Spangler (November 20, 1848-January 22, 1915)
Luther Burbank (March 7, 1849-April 11, 1926)
Andrew Jackson Beard (March 29, 1849-May 10, 1921)
Victor Leaton Ochoa (1850-c. 1945)
Oliver Heaviside (May 18, 1850-February 3, 1925)
Karl Ferdinand Braun (June 6, 1850-April 20, 1918)
John Milne (December 30, 1850-July 31, 1913)
Emile Berliner (May 20, 1851-August 3, 1929)
John Harvey Kellogg (February 26, 1852-December 14, 1943)
Jan Ernst Matzeliger (September 15, 1852-August 24, 1889)
André Michelin (January 16, 1853-April 4, 1931)

Hudson Maxim (February 3, 1853-May 6, 1927)
Elihu Thomson (March 29, 1853-March 13, 1937)
Heike Kamerlingh Onnes (September 21, 1853-February 21, 1926)
Hertha Marks Ayrton (April 28, 1854-August 26, 1923)
Ottmar Mergenthaler (May 11, 1854-October 28, 1899)
Charles Parsons (June 13, 1854-February 11, 1931)
George Eastman (July 12, 1854-March 14, 1932)
King Camp Gillette (January 5, 1855-July 9, 1932)
John Moses Browning (January 21, 1855-November 26, 1926)
William Seward Burroughs (January 28, 1855-September 15, 1898)
Granville T. Woods (April 23, 1856-January 30, 1910)
Edward Goodrich Acheson (May 9, 1856-July 6, 1931)
Nikola Tesla (July 9/10, 1856-January 7, 1943)
Heinrich Hertz (February 22, 1857-January 1, 1894)
Frank J. Sprague (July 25, 1857-October 25, 1934)
Ida H. Hyde (September 8, 1857-August 22, 1945)
Konstantin Tsiolkovsky (September 17, 1857-September 19, 1935)
Rudolf Diesel (March 18, 1858-September 29, 1913)
Édouard Michelin (June 23, 1859-August 25, 1940)
Herman Hollerith (February 29, 1860-November 17, 1929)
Ignaz Schwinn (April 1, 1860-1948)
Willem Einthoven (May 21, 1860-September 28, 1927)
Alexander Winton (June 20, 1860-June 21, 1932)
Elmer Ambrose Sperry (October 12, 1860 [baptized]-June 16, 1930)
John T. Thompson (December 31, 1860-June 21, 1940)
Peter Cooper Hewitt (May 5, 1861-August 25, 1921)
George Washington Carver (July 12, 1861?-January 5, 1943)
Jesse W. Reno (August 4, 1861-June 2, 1947)
Auguste Lumière (October 19, 1862-April 10, 1954)
Henry Ford (July 30, 1863-April 7, 1947)
Leo Hendrik Baekeland (November 14, 1863-February 23, 1944)
Charles Martin Hall (December 6, 1863-December 27, 1914)
Ransom Eli Olds (June 3, 1864-August 26, 1950)
Louis Lumière (October 5, 1864-June 6, 1948)
Richard Zsigmondy (April 1, 1865-September 24, 1929)
Charles Proteus Steinmetz (April 6, 1865-October 26, 1923)
Arthur James Arnot (August 26, 1865-October 15, 1946)
Edwin Binney (1866-December 18, 1934)
Herbert Henry Dow (February 26, 1866-October 15, 1930)
Reginald Aubrey Fessenden (October 6, 1866-July 22, 1932)
Sakichi Toyoda (February 14, 1867-October 30, 1930)
Eldridge R. Johnson (February 18, 1867-November 14, 1945)
Wilbur Wright (April 16, 1867-May 30, 1912)
Frank Lloyd Wright (June 8, 1867-April 9, 1959)
Madam C. J. Walker (December 23, 1867-May 25, 1919)
Charles E. Taylor (May 24, 1868-June 30, 1956)
Fritz Haber (December 9, 1868-January 29, 1934)
Hiram Percy Maxim (September 2, 1869-February 17, 1936)
Nils Gustaf Dalén (November 30, 1869-December 9, 1937)
Georges Claude (September 24, 1870-May 23, 1960)
H. Cecil Booth (July 4, 1871-January 18, 1955)
Orville Wright (August 19, 1871-January 30, 1948)
Jacques Edwin Brandenberger (October 19, 1872-July 13, 1954)
Lee De Forest (August 26, 1873-June 30, 1961)
William David Coolidge (October 23, 1873-February 3, 1975)
Guglielmo Marconi (April 25, 1874-July 20, 1937)
Carl Bosch (August 27, 1874-April 26, 1940)
Miller Reese Hutchison (August 6, 1876-February 16, 1944)
Charles F. Kettering (August 29, 1876-November 25, 1958)
Willis Carrier (November 26, 1876-October 9, 1950)
Frederick Gardner Cottrell (January 10, 1877-November 16, 1948)
Garrett Augustus Morgan (March 4, 1877-July 27, 1963)
Joshua Lionel Cowen (August 25, 1877-September 8, 1965)
Jacob Schick (September 16, 1877-July 3, 1937)
Ernst Alexanderson (January 25, 1878-May 14, 1975)
Glenn H. Curtiss (May 21, 1878-July 23, 1930)
Lillian Evelyn Gilbreth (May 24, 1878-January 2, 1972)
Albert Einstein (March 14, 1879-April 18, 1955)
Bernhard Voldemar Schmidt (March 30, 1879-December 1, 1935)
Irving Langmuir (January 31, 1881-August 16, 1959)

Hans Geiger (September 30, 1882-September 24, 1945)
Robert H. Goddard (October 5, 1882-August 10, 1945)
Friedrich Bergius (October 11, 1884-March 30, 1949)
Theodor Svedberg (August 30, 1884-February 25, 1971)
Clarence Birdseye (December 9, 1886-October 7, 1956)
Beulah Louise Henry (September 28, 1887-February, 1973)
Selman Abraham Waksman (July 22, 1888-August 16, 1973)
Andrei Nikolayevich Tupolev (November 10, 1888-December 23, 1972)
Igor Sikorsky (May 25, 1889-October 26, 1972)
Vladimir Zworykin (July 30, 1889-July 29, 1982)
Edwin H. Armstrong (December 18, 1890-January 31, 1954)
Walther Bothe (January 8, 1891-February 8, 1957)
Sir Robert Alexander Watson-Watt (April 13, 1892-December 5, 1973)
Caresse Crosby (April 20, 1892-January 24, 1970)
Frederick McKinley Jones (May 17, 1892-February 21, 1961)
Pyotr Leonidovich Kapitsa (July 8, 1894-April 8, 1984)
Percy L. Spencer (July 9, 1894-September 8, 1970)
William Francis Giauque (May 12, 1895-March 28, 1982)
R. Buckminster Fuller (July 12, 1895-July 1, 1983)
Wallace Hume Carothers (April 27, 1896-April 29, 1937)
Katharine Burr Blodgett (January 10, 1898-October 12, 1979)
Leo Szilard (February 11, 1898-May 30, 1964)
Percy Lavon Julian (April 11, 1899-April 19, 1975)
Georg von Békésy (June 3, 1899-June 13, 1972)
Richard G. Drew (June 22, 1899-December 14, 1980)
Leopold Mannes (December 26, 1899-August 11, 1964)
Charles Francis Richter (April 26, 1900-September 30, 1985)
Leopold Godowsky, Jr. (May 27, 1900-February 18, 1983)
Dennis Gabor (June 5, 1900-February 8, 1979)
Maria Telkes (December 12, 1900-December 2, 1995)

1901-1950

Ernest Orlando Lawrence (August 8, 1901-August 27, 1958)
Enrico Fermi (September 29, 1901-November 28, 1954)
Charles Stark Draper (October 2, 1901-July 25, 1987)
Walt Disney (December 5, 1901-December 15, 1966)
Walter H. Brattain (February 10, 1902-October 13, 1987)
Calvin Fuller (May 25, 1902-October 28, 1994)
Bill Lear (June 26, 1902-May 14, 1978)
Felix Wankel (August 13, 1902-October 9, 1988)
Harold E. Edgerton (April 6, 1903-January 4, 1990)
John Vincent Atanasoff (October 4, 1903-June 15, 1995)
Ernest Thomas Sinton Walton (October 6, 1903-June 25, 1995)
George Stibitz (April 20, 1904-January 31, 1995)
J. Robert Oppenheimer (April 22, 1904-February 18, 1967)
Charles Richard Drew (June 3, 1904-April 1, 1950)
Edwin Albert Link (July 26, 1904-September 7, 1981)
Gerald Pearson (March 31, 1905-October 25, 1987)
M. Stanley Livingston (May 25, 1905-August 25, 1986)
Karl G. Jansky (October 22, 1905-February 14, 1950)
Semi Joseph Begun (December 2, 1905-January 5, 1995)
Chester F. Carlson (February 8, 1906-September 19, 1968)
Philo T. Farnsworth (August 19, 1906-March 11, 1971)
Max Tishler (October 30, 1906-March 18, 1989)
Peter Carl Goldmark (December 2, 1906-December 7, 1977)
Grace Murray Hopper (December 9, 1906-January 1, 1992)
Ernst Ruska (December 25, 1906-May 30, 1988)
Sir Frank Whittle (June 1, 1907-August 8, 1996)
Georges de Mestral (June 19, 1907-February 8, 1990)
Earl S. Tupper (July 28, 1907-October 5, 1983)
John William Mauchly (August 30, 1907-January 8, 1980)
Ruth Patrick (November 26, 1907)
Edward Teller (January 15, 1908-September 9, 2003)

John Bardeen (May 23, 1908-January 30, 1991)
Willard F. Libby (December 17, 1908-September 8, 1980)
Edwin Herbert Land (May 7, 1909-March 1, 1991)
Jacob Rabinow (January 8, 1910-September 11, 1999)
William Shockley (February 13, 1910-August 12, 1989)
John R. Pierce (March 27, 1910-April 2, 2002)
Dorothy Crowfoot Hodgkin (May 12, 1910-July 29, 1994)
Sir Christopher Cockerell (June 4, 1910-June 1, 1999)
Jacques Cousteau (June 11, 1910-June 25, 1997)
Konrad Zuse (June 22, 1910-December 18, 1995)
Roy J. Plunkett (June 26, 1910-May 12, 1994)
Willem Johan Kolff (February 14, 1911-February 11, 2009)
Erwin Wilhelm Müller (June 13, 1911-May 17, 1977)
Luis W. Álvarez (June 13, 1911-September 1, 1988)
Hans Joachim Pabst von Ohain (December 14, 1911-March 13, 1998)
Ivan A. Getting (January 18, 1912-October 11, 2003)
Wernher von Braun (March 23, 1912-June 16, 1977)
Glenn Theodore Seaborg (April 19, 1912-February 25, 1999)
Alan Mathison Turing (June 23, 1912-June 7, 1954)
William Redington Hewlett (May 20, 1913-January 12, 2001)
Otto Wichterle (October 27, 1913-August 18, 1998)
Hugh Le Caine (May 27, 1914-July 3, 1977)
Jonas Salk (October 28, 1914-June 23, 1995)
Les Paul (June 9, 1915-August 13, 2009)
Charles Hard Townes (July 28, 1915)
James Hillier (August 22, 1915-January 15, 2007)
John C. Sheehan (September 23, 1915-March 21, 1992)
Marvin Camras (January 1, 1916-June 23, 1995)
Claude Elwood Shannon (April 30, 1916-February 24, 2001)
Sir Alan Walsh (December 19, 1916-August 3, 1998)
Gertrude Belle Elion (January 23, 1918-February 21, 1999)
Alfred J. Gross (February 22, 1918-December 21, 2000)
Clifford Berry (April 19, 1918-October 30, 1963)
Jay Wright Forrester (July 14, 1918)
John Alexander Hopps (1919-November 24, 1998)
John Presper Eckert (April 9, 1919-June 3, 1995)
Godfrey Newbold Hounsfield (August 28, 1919-August 12, 2004)
Wilson Greatbatch (September 6, 1919)
H. Tracy Hall (October 20, 1919-July 25, 2008)
An Wang (February 7, 1920-March 24, 1990)
Gordon Gould (July 17, 1920-September 16, 2005)
Charles P. Ginsburg (July 27, 1920-April 9, 1992)
Otis Boykin (August 29, 1920-March, 1982)
Arthur L. Schawlow (May 5, 1921-April 28, 1999)
Rosalyn Yalow (July 19, 1921)
Stanford Ovshinsky (November 24, 1922)
Roscoe Koontz (December 16, 1922-May 17, 1997)
Paul Winchell (December 21, 1922-June 24, 2005)
Helen M. Free (February 20, 1923)
Jerome H. Lemelson (July 18, 1923-October 1, 1997)
Stephanie Kwolek (July 31, 1923)
Carl Djerassi (October 29, 1923)
Jack St. Clair Kilby (November 8, 1923-June 20, 2005)
Bette Nesmith Graham (March 23, 1924-May 12, 1980)
Willard S. Boyle (August 19, 1924)
Seymour Cray (September 28, 1925-October 5, 1996)
Paul B. MacCready (September 29, 1925-August 28, 2007)
Ken Olsen (February 20, 1926)
Erna Schneider Hoover (June 19, 1926)
Robert Steven Ledley (June 28, 1926)
Donald A. Glaser (September 21, 1926)
Ali Javan (December 26, 1926)
Lewis Urry (January 29, 1927-October 19, 2004)
Emmett Leith (March 12, 1927-December 23, 2005)
Karl Alexander Müller (April 20, 1927)
Theodore Harold Maiman (July 11, 1927-May 5, 2007)
Robert Norton Noyce (December 12, 1927-June 30, 1990)
Don Wetzel (1928)
Nick Holonyak, Jr. (November 3, 1928)
Martin Cooper (December 26, 1928)
Rangaswamy Srinivasan (February 28, 1929)
Meredith C. Gourdine (September 26, 1929-November 20, 1998)
Patsy O'Connell Sherman (September 15, 1930-February 11, 2008)
Alan Shugart (September 27, 1930-December 12, 2006)
James Russell (February 23, 1931)
Heinrich Rohrer (June 6, 1933)
James Fergason (January 12, 1934)
Henry Thomas Sampson (April 22, 1934)
Robert Moog (May 23, 1934-August 21, 2005)
Stanley Norman Cohen (February 17, 1935)
Raymond Damadian (March 16, 1936)
Herbert Wayne Boyer (July 10, 1936)

Robert Charles Gallo (March 23, 1937)
Ted Hoff (October 28, 1937)
Sheila Widnall (July 13, 1938)
Bob Kahn (December 23, 1938)
Sumio Iijima (May 2, 1939)
George R. Carruthers (October 1, 1939)
George Edward Alcorn (March 22, 1940)
Taylor Gunjin Wang (June 16, 1940)
Federico Faggin (December 1, 1941)
Patricia Bath (November 4, 1942)
Valerie L. Thomas (February 1, 1943)
Nolan K. Bushnell (February 5, 1943)
Burt Rutan (June 17, 1943)
Vinton Gray Cerf (June 23, 1943)
Kary B. Mullis (December 28, 1944)
Toyoichi Tanaka (January 4, 1946-May 20, 2000)
Mary-Claire King (February 27, 1946)
Robert Metcalfe (April 7, 1946)
Robert Jarvik (May 11, 1946)
Robert Cailliau (January 26, 1947)
Gerd Binnig (July 20, 1947)
Naomi L. Nakao (January 13, 1948)
Ray Kurzweil (February 12, 1948)
Ashok Gadgil (1950)
Alec Jeffreys (January 9, 1950)
J. Georg Bednorz (May 16, 1950)
Steve Wozniak (August 11, 1950)

1951-

Dean Kamen (April 5, 1951)
Shuji Nakamura (May 22, 1954)
Philip Emeagwali (August 23, 1954)
Steve Jobs (February 24, 1955)
Tim Berners-Lee (June 8, 1955)
Bill Gates (October 28, 1955)
Mark Dean (March 2, 1957)
Tony Fadell (1969)
Marc Andreessen (July 9, 1971)
Larry Page (March 26, 1973)

TIME LINE

The time line below lists more than five hundred milestones in the history of technology: major inventions and their approximate dates of emergence, along with key events in the history of science. These developments appear in boldface, followed by the name or names of the inventors in parentheses, where these individuals are known. A brief description of the significance of the milestone follows.

—Charles W. Rogers, Southwestern Oklahoma State University, Department of Physics

DATE	INVENTION/MILESTONE
2,500,000 B.C.E.	**Stone tools**: Stone tools, used by *Homo habilis* and perhaps other hominids, first appear in the Lower Paleolithic age (Old Stone Age).
400,000 B.C.E.	**Controlled use of fire**: The earliest controlled use of fire by humans may have been about this time.
200,000 B.C.E.	**Stone tools using the prepared core technique**: Stone tools made by chipping away flakes from the stones from which they were made appear in the Middle Paleolithic age.
100,000-50,000 B.C.E.	**Widespread use of fire by humans**: Fire is used for heat, light, food preparation, and driving off nocturnal predators. It is later used to fire pottery and smelt metals.
100,000-50,000 B.C.E.	**Language**: At some point, language became abstract, enabling the speaker to discuss intangible concepts such as the future.
16,000 B.C.E.	**Earliest pottery**: The earliest pottery was fired by putting it in a bonfire. Later it was placed in a trench kiln. The earliest ceramic is a female figure from about 29,000 to 25,000 B.C.E., fired in a bonfire.
10,000 B.C.E.	**Domesticated dogs**: Dogs seem to have been domesticated first in East Asia.
10,000 B.C.E.	**Agriculture**: Agriculture allows people to produce more food than is needed by their family, freeing humans from the need to lead nomadic lives and giving them free time to develop astronomy, art, philosophy, and other pursuits.
10,000 B.C.E.	**Archery**: Archery allows human hunters to strike a target from a distance while remaining relatively safe.
10,000 B.C.E.	**Domesticated sheep**: Sheep seem to have been domesticated first in Southwest Asia.
9000 B.C.E.	**Domesticated pigs**: Pigs seem to have been domesticated first in the Near East and in China.
8000 B.C.E.	**Domesticated cows**: Cows seem to have been domesticated first in India, the Middle East, and sub-Saharan Africa.
7500 B.C.E.	**Mud bricks**: Mud-brick buildings appear in desert regions, offering durable shelter. The citadel in Bam, Iran, the largest mud-brick building in the world, was built before 500 B.C.E., and was largely destroyed by an earthquake in 2003.
7500 B.C.E.	**Domesticated cats**: Cats seem to have been domesticated first in the Near East.
6000 B.C.E.	**Domesticated chickens**: Chickens seem to have been domesticated first in India and Southeast Asia.
6000 B.C.E.	**Scratch plow**: The earliest plow, a stick held upright by a frame and pulled through the topsoil by oxen, is in use.
6000 B.C.E.	**Electrum**: The substance is a natural blend of gold and silver, pale yellow in color like amber. The name “electrum” comes from the Greek word for amber.
6000 B.C.E.	**Gold**: Gold is discovered—possibly the first metal to be recognized as such.
6000-4000 B.C.E.	**Potter’s wheel**: The potter’s wheel is developed, allowing for the relatively rapid formation of radially symmetric items, such as pots and plates, from clay.

DATE	INVENTION/MILESTONE
5000 B.C.E.	**Wheel**: The chariot wheel and the wagon wheel evolve—possibly from the potter's wheel. One of humankind's oldest and most important inventions, the wheel leads to the invention of the axle and a bearing surface.
4200 B.C.E.	**Copper**: Egyptians mine and smelt copper.
4000 B.C.E.	**Moldboard plow**: The moldboard plow cut a furrow and simultaneously lifted the soil and turned it over, bringing new nutrients to the surface.
4000 B.C.E.	**Domesticated horses**: Horses seem to have been domesticated first on the Eurasian steppes.
4000 B.C.E.	**Silver**: Silver can be found as a metal in nature, but this is rare. It is harder than gold, but softer than copper.
4000 B.C.E.	**Domesticated honeybees**: The keeping of bee hives for honey arises in many different regions.
4000 B.C.E.	**Glue**: Ancient Egyptian burial sites contain clay pots that have been glued together with tree sap.
3500 B.C.E.	**Lead**: Lead is first extruded from galena (lead sulfide), which can be made to release its lead simply by placing it in a hot campfire.
3000 B.C.E.	**Bronze**: Bronze, an alloy of copper and tin, is developed. Harder than copper and stronger than wrought iron, it resists corrosion better than iron.
3000 B.C.E.	**Cuneiform**: The method of writing now known as cuneiform began as pictographs but evolved into more abstract patterns of wedge-shaped (cuneiform) marks, usually impressed into wet clay. This system of marks made complex civilization possible, since it allowed record keeping to develop.
3000 B.C.E.	**Fired bricks**: Humans begin to fire bricks, creating more durable building materials that (because of their regular size and shape) are easier to lay than stones.
3000 B.C.E.	**Pewter**: The alloy pewter is developed. It is 85 to 99 percent tin, with the remainder being copper, antimony, and lead; copper and antimony make the pewter harder. Pewter's low melting point, around 200 degrees Celsius, makes it a valuable material for making vessels that hold hot substances.
2700 B.C.E.	**Plumbing**: Earthenware pipes sealed together with asphalt first appear in the Indus Valley civilization. Greeks, Romans, and others provided cities with fresh water and a way to carry off sewage.
2650 B.C.E.	**Horse-drawn chariot** (Huangdi): Huangdi—a legendary patriarch of China—is possibly a combination of many men. He is said to have invented—in addition to the chariot—military armor, ceramics, boats, crop rotation, and more.
2600 B.C.E.	**Inclined plane**: Inclined planes are simple machines and were used in building Egypt's pyramids. Pushing an object up a ramp requires less force than lifting it directly, although the use of a ramp requires that the load be pushed a longer distance.
1750 B.C.E.	**Tin**: Tin is alloyed with copper to form bronze.
1730 B.C.E.	**Glass beads**: Red-brown glass beads found in South Asia are the oldest known human-formed glass objects.
1600 B.C.E.	**Mercury**: Mercury can easily be released from its ore (such as cinnabar) by simply heating it.
1500 B.C.E.	**Iron**: Iron, stronger and more plentiful than bronze, is first worked in West Asia, probably by the Hittites. It could hold a sharper edge, but it had to be smelted at higher temperatures, making it more difficult to produce than bronze.
1500 B.C.E.	**Zinc**: Zinc is alloyed with copper to form brass, but it will not be recognized as a separate metal until 1746.
1000 B.C.E.	**Concrete**: The ancient Romans build arches, vaults, and walls out of concrete.
1000 B.C.E.	**Crossbow**: The crossbow seems to come from ancient China. Crossbows can be made to be much more powerful than a normal bow.
700 B.C.E.	**Magnifying glass**: An Egyptian hieroglyph seems to show a magnifying glass.

Date	Invention/Milestone
350 B.C.E.	**Compass**: Ancient Chinese used lodestones and later magnetized needles mostly to harmonize their environments with the principles of feng shui. Not until the eleventh century are these devices used primarily for navigation.
350-100 B.C.E.	**Scientific method** (Aristotle): Aristotle develops the first useful set of rules attempting to explain how scientists do science.
300 B.C.E.	**Screw**: Described by Archimedes, the screw is a simple machine that appears to be a ramp wound around a shaft. It converts a smaller turning force to a larger vertical force, as in a screw jack.
300 B.C.E.	**Lever**: Described by Archimedes, the lever is a simple machine that allows one to deliver a larger force to a load than the force with which one pushes on the lever.
300 B.C.E.	**Pulley**: Described by Archimedes, the pulley is a simple machine that allows one to change the direction of the force delivered to the load.
215 B.C.E.	**Archimedes' principle** (Archimedes of Syracuse): Archimedes describes his law of displacement: A floating body displaces an amount of fluid whose weight is equal to the weight of the body.
200 B.C.E.	**Astrolabe**: A set of engraved disks and indicators becomes known as the astrolabe. When aligned with the stars, the astrolabe can be used to determine the rising and setting times of the Sun and certain stars, establish compass directions, and determine local latitude.
40 C.E.	**Ptolemy's geocentric system** (Ptolemy): A world system with the Earth in the center with the Moon, Venus, Mercury, Sun, Mars, Jupiter, Saturn, and fixed stars surrounding it, the geocentric Ptolemaic system would remain the most widely accepted cosmology for the next fifteen hundred years.
90 C.E.	**Aeolipile** (Hero of Alexandria): The aeolipile—a steam engine that escaping steam causes to rotate like a lawn sprinkler—is developed.
105	**Paper and paper making** (Cai Lun): Although papyrus paper already existed, Cai Lun creates paper from a mixture of fibrous materials softened into a wet pulp that is spread flat and dried. The material is strong and can be cheaply mass-produced.
250	**Force pump** (Ctesibius of Alexandria): Ctesibius develops a device that shoots a jet of water, like a fire extinguisher.
815	**Algebra** (al-Khwārizmī): al-Khwārizmī develops the mathematics that solves problems by using letters for unknowns (variables) and expressing their relationships with equations.
877	**Maneuverable glider** (ʿAbbas ibn Firnas): A ten-minute controlled glider flight is first achieved.
1170	**Water-raising machines** (al-Jazarī): In addition to developing machines that can transport water to higher levels, al-Jazarī invents water clocks and automatons.
1260	**Scientific method** (Roger Bacon): Bacon develops rules for explaining how scientists do science that emphasize empiricism and experimentation over accepted authority.
1284	**Eyeglasses for presbyopia** (Salvino d'Armate): D'Armate is credited with making the first wearable eyeglasses in Italy, with convex lenses. These spectacles assist those with farsightedness, such as the elderly.
1439	**Printing press** (Johann Gutenberg): Gutenberg combined a press, oil-based ink, and movable type made from an alloy of lead, zinc, and antimony to create a revolution in printing, allowing mass-produced publications that could be made relatively cheaply and disseminated to people other than the wealthy.
1450	**Eyeglasses for the nearsighted** (Nicholas of Cusa): Correcting nearsightedness requires diverging lenses, which are more difficult to make than convex lenses.
1485	**Dream of flight** (Leonardo da Vinci): On paper, Leonardo designed a parachute, great wings flapped by levers, and also a person-carrying machine with wings to be flapped by the person. Although these flying devices were never successfully realized, the designs introduced the modern quest for aeronautical engineering.

Date	Invention/Milestone
1543	**Copernican (heliocentric) universe**: Copernicus publishes *De revolutionibus* (*On the Revolutions of the Heavenly Spheres*), in which he refutes geocentric Ptolemaic cosmology and proposes that the Sun, not Earth, lies at the center of the then-known universe (the solar system).
1569	**Mercator projection** (Gerardus Mercator): The Mercator projection maps the Earth's surface onto a series of North/South cylinders.
1594	**Logarithms** (John Napier): Napier's logarithms allow the simplification of complex multiplication and division problems.
1595	**Parachute** (Faust Vrančić): Vrančić publishes a book describing sixty new machines, one of which is a design for a parachute that might have worked.
1596	**Flush toilet** (Sir John Harington): Harington's invention is a great boone to those previously assigned to empty the "chamber pots."
1604	**Compound microscope** (Zacharias Janssen): Janssen, a lens crafter, experiments with lenses, leading to both the microscope and the telescope.
1607	**Air and clinical thermometers** (Santorio Santorio): Santorio develops a small glass bulb that can be placed in a person's mouth, with a long, thin neck that is placed in a beaker of water. The water rises or falls as the person's temperature changes.
1608	**Refracting telescope** (Hans Lippershey): Lippershey is one of several who can lay claim on developing the early telescope.
1609	**Improved telescope** (Galileo Galilei): Galileo grinds and polishes his own lenses to make a superior telescope. Galileo will come to be known as the father of modern science.
1629	**Steam turbine** (Giovanni Branca): Branca publishes a design for a steam turbine, but it requires machining that is too accurate to be built in his day.
1644	**Barometer** (Evangelista Torricelli): Torricelli develops a mercury-filled barometer, in which the height of the mercury in the tube is a measure of atmospheric pressure.
1650	**Vacuum pump** (Otto von Guericke): After demonstrating the existence of a vacuum, von Guericke explores its properties with other experiments.
1651	**Hydraulic press** (Blaise Pascal): Pascal determines that hydraulics can multiply force. For example, a 50-pound force applied to the hydraulic press might exert 500 pounds of force on an object in the press.
1656	**Pendulum clock** (Christiaan Huygens): Huygens discovers that, for small oscillations, a pendulum's period is independent of the size of the pendulum's swing, so it can be used to regulate the speed of a clock.
1663	**Gregorian telescope** (James Gregory): The Gregorian telescope produces upright images and therefore becomes useful as a terrestrial telescope.
1666	**The calculus** (Sir Isaac Newton): Newton (and independently Gottfried Wilhelm Leibniz) develop the calculus in order to calculate the gravitational effect of all of the particles of the Earth on another object such as a person.
1670	**Spiral spring balance watch** (Robert Hooke): Hooke is also credited as the author of the principle that describes the general behavior of springs, known as Hooke's law.
1672	**Leibniz's calculator** (Gottfried Wilhelm Leibniz): Leibniz develops a calculator that can add, subtract, multiply, and divide, as well as the binary system of numbers used by computers today.
1674	**Improvements to the simple microscope** (Antoni van Leeuwenhoek): Leeuwenhoek, a lens grinder, applies his lenses to the simple microscope and uses his microscope to observe tiny protozoa in pond water.
1698	**Savery pump** (Thomas Savery): Savery's pump was impractical to build, but it served as a prototype for Newcomen's steam engine.

DATE	INVENTION/MILESTONE
1700	**Piano** (Bartolomeo Cristofori): Cristofori, a harpsichord maker, constructs an instrument with keys that can be used to control the force with which hammers strike the instrument's strings, producing sound that ranges from *piano* (soft) to *forte* (loud)—hence the name "pianoforte," later shortened to "piano."
1701	**Tull seed drill** (Jethro Tull): Before the seed drill, seeds were still broadcast by hand.
1709	**Iron ore smelting with coke** (Abraham Darby): Darby develops a method of smelting iron ore by using coke, rather than charcoal, which at the time was becoming scarce. Coke is made by heating coal and driving off the volatiles (which can be captured and used).
1712	**Atmospheric steam engine** (Thomas Newcomen): Newcomen's engine is developed to pump water out of coal mines.
1714	**Mercury thermometer, Fahrenheit temperature scale** (Daniel Gabriel Fahrenheit): Fahrenheit uses mercury in a glass thermometer to measure temperature over the entire range for liquid water.
1729	**Flying shuttle** (John Kay): On a loom, the shuttle carries the horizontal thread (weft or woof) and weaves it between the vertical threads (warp). Kay develops a shuttle that is named "flying" because it is so much faster than previous shuttles.
1738	**Flute Player and Digesting Duck automatons** (Jacques de Vaucanson): De Vaucanson builds cunning, self-operating devices, or automatons (robots) to charm viewers.
1745-1746	**Leiden jar** (Pieter van Musschenbroek and Ewald Georg von Kleist): Von Kleist (1745) and Musschenbroek (1746) independently develop the Leiden jar, an early type of capacitor used for storing an electric charge.
1746	**Clinical trials prove that citrus fruit cures scurvy** (James Lind): Others had suggested citrus fruit as a cure for scurvy, but Lind gives scientific proof. It still will be another fifty years before preventive doses of foods containing vitamin C are routinely provided for British sailors.
1752	**Franklin stove** (Benjamin Franklin): Franklin develops a stove that allows more heat to radiate into a room than what goes up the chimney.
1752	**Lightning rod** (Benjamin Franklin): Franklin devises an iron-rod apparatus to attach to houses and other structures in order to ground them, preventing damage during lightning storms.
1756	**Wooden striking clock** (Benjamin Banneker): Banneker's all-wood striking clock operates for the next fifty years. Banneker also prints a series of successful scientific almanacs during the 1790's.
1757	**Nautical sextant** (John Campbell): When used with celestial tables, Campbell's sextant allows ships to navigate to within sight of their destinations.
1762	**Marine chronometers** (John Harrison): An accurate chronometer was necessary to determine a ship's position at sea, solving the pressing quest for longitude.
1764	**Spinning jenny** (James Hargreaves): Hargreaves develops a machine for spinning several threads at a time, revolutionizing the textile industry and laying a foundation for the Industrial Revolution.
1765	**Improved steam engine** (James Watt): A steam condenser separate from the working pistons make Watt's engine significantly more efficient than Newcomen's engine of 1712.
1767	**Dividing engine** (Jesse Ramsden): Ramsden develops a machine that automatically and accurately marks calibrated scales.
1767	**Spinning machine** (Sir Richard Arkwright): Arkwright develops a device to spin fibers quickly into consistent, uniform thread.
1770	**Steam dray** (Nicolas-Joseph Cugnot): Cugnot builds his three-wheeled *fardier à vapeur* to move artillery; the prototype pulls 2.5 metric tons at 2 kilometers per hour.
1772	**Soda water** (Joseph Priestley): Priestley creates the first soda water, water charged with carbon dioxide gas. The next year, he develops an apparatus for collecting gases by mercury displacement that would otherwise dissolve in water.

Date	Invention/Milestone
1776	**Bushnell's submarine** (David Bushnell): Bushnell builds the first attack submarine; used unsuccessfully against British ships in the Revolutionary War, it nevertheless advances submarine technology.
1781	**Uranus discovered** (Sir William Herschel): Herschel observes what he first believes to be a comet; further observation establishes it as a planet eighteen times farther from the Sun than the Earth is.
1782	**Hot-air balloon** (Étienne-Jacques and Joseph-Michel Montgolfier): Shaped like an onion dome and carrying people aloft, the Montgolfiers' hot-air balloon fulfills the fantasy of human flight.
1783	**Parachutes** (Louis-Sébastien Lenormand): Lenormand jumps from an observatory tower using his parachute and lands safely.
1784	**Improved steam engine** (William Murdock): In an age when much focus was on steam technology, Murdock works to improve steam pumps that remove water from mines. He will go on to invent coal-gas lighting in 1794.
1784	**Bifocals** (Benjamin Franklin): Tired of changing his spectacles to see things at close range as opposed to objects farther away, Franklin designs eyeglasses that incorporate both myopia-correcting and presbyopia-correcting lenses.
1784	**Power loom** (Edmund Cartwright): Cartwright's power loom forms a major advance in the Industrial Revolution.
1785	**Automated flour mill** (Oliver Evans): Evans's flour mill lays the foundation for continuous production lines. In 1801, he will also invent a high-pressure steam engine.
1790	**Steamboat** (John Fitch): Fitch not only invents the steamboat but also proves its practicality by running a steamboat service along the Delaware River.
1792	**Great Clock** (Thomas Jefferson): Jefferson's clock, visible and audible both within Monticello and outside, across his plantation, is designed to maintain efficiency. He also invented an improved portable copying press (1785) and will go on to invent an improved ox plow (1794).
1793	**Cotton gin** (Eli Whitney): Whitney's engine to separate cotton seed from the fiber transformed the American South, both bolstering the institution of slavery and growing the "cotton is king" economy of the Southern states. Five years later, Whitney develops an assembly line for muskets using interchangeable parts.
1796	**Rumford stove** (Benjamin Thompson): The Rumford stove—a large, institutional stove—uses several small fires to heat the stove top uniformly.
1796	**Smallpox vaccination** (Edward Jenner): Jenner's vaccine will save millions from death, culminating in the eradication of smallpox in 1979.
1799	**Voltaic pile/electric battery** (Alessandro Volta): Volta creates a pile—a stack of alternating copper and zinc disks separated by brine-soaked felt—that supplies a continuous current and sets the stage for the modern electric battery.
1804	**Monoplane glider** (George Cayley): Cayley develops a heavier-than-air fixed-wing glider that inaugurates the modern field of aeronautics. Later models carry a man and lead directly to the Wright brothers' airplane.
1805	**Electroplating** (Luigi Brugnatelli): Brugnatelli develops the method of electroplating by connecting something to be plated to one pole of a battery (Voltaic pile) and connecting a bit of the plating metal to the other pole of the battery, placing both in a suitable solution.
1806	**Steam locomotive** (Richard Trevithick): After James Watt's patent for the steam engine expires in 1800, Trevithick develops a working steam locomotive. By 1806 he has developed his improved steam engine, named the Cornish engine, which sees worldwide dissemination.
1807	**Paddle-wheel steamer** (Robert Fulton): Fulton's steamboat becomes far more commercially successful than those of his competitors.

DATE	INVENTION/MILESTONE
1808	**Law of combining volumes for gases** (Joseph-Louis Gay-Lussac): Gay-Lussac discovers that, when gaseous elements combine to make a compound, the volumes involved are always simple whole-number ratios.
1810	**Preserving food in sealed glass bottles** (Nicolas Appert): Appert answers Napoleon's call to preserve food in a way that allows his soldiers to carry it with them: He processes food in sealed, air-tight glass bottles.
1810	**Preserving food in tin cans** (Peter Durand): Durand follows Nicolas Appert in preserving food for the French army, but he uses tin-coated steel cans in place of the breakable bottles.
1815	**Miner's safety lamp** (Sir Humphry Davy): Davy devises a miner's safety lamp in which the flame is surrounded by wire gauze to cool combustion gases so that the mine's methane-air mixture will not be ignited.
1816	**Macadamization** (John Loudon McAdam): McAdam designs a method of paving roads with crushed stone bound with gravel on a base of large stones. The roadway is slightly convex, to shed water.
1816	**Kaleidoscope** (Sir David Brewster): The name for Brewster's kaleidoscope comes from the Greek words *kalos* (beautiful), *eidos* (form), and *scopos* (watcher). "Kaleidoscope," therefore, literally means "beautiful form watcher."
1816	**Stirling engine** (Robert Stirling): The Stirling engine proves to be an efficient engine that uses hot air as a working fluid.
1819	**Stethoscope** (René-Théophile-Hyacinthe Laënnec): Laënnec invents the stethoscope to avoid the impropriety of placing his ear on the chest of a female heart patient.
1820	**Dry "scouring"** (Thomas L. Jennings): Jennings discovered that turpentine would remove most stains from clothes without the wear associated with washing them in hot water. His method becomes the basis for modern dry cleaning.
1821	**Braille alphabet** (Louis Braille): Braille develops a tactile alphabet—a system of raised dots on a surface—that allows the blind to read by feel.
1821	**Diffraction grating** (Joseph von Fraunhofer): Fraunhofer's diffraction grating separates incident light by color into a rainbow pattern. The various discrete patterns reveal the structure of specific atomic nuclei, making it possible to identify the chemical compositions of various substances.
1822	**Difference engine** (Charles Babbage): Babbage's "engine" was a programmable mechanical device used to calculate the value of a polynomial—a precursor to today's modern computers.
1823	**Waterproof fabric used in raincoats** (Charles Macintosh): Macintosh patents a waterproof fabric consisting of soluble rubber between two pieces of cloth. Raincoats made of the fabric are still often called mackintoshes (macs), especially in England.
1824	**Astigmatism-correcting lenses** (George Biddell Airy): Airy develops cylindrical lenses that correct astigmatism. An astronomer, Airy will go on to design a method of correcting compasses used in ship navigation and the altazimuth telescope. He becomes England's astronomer royal in 1835.
1825	**Electromagnet** (William Sturgeon): Sturgeon builds a U-shaped, soft iron bar with a coil of varnished copper wire wrapped around it. When a voltaic current is passed through wire, the bar becomes magnetic—the world's first electromagnet.
1825	"**Steam waggon**" (John Stevens): Stevens builds the first steam locomotive to be manufactured in the United States.
1825	**Bivalve vaginal speculum** (Marie Anne Victoire Boivin): Boivin develops the tool now widely used by gynecologists in the examination of the vagina and cervix.
1827	**Matches** (John Walker): Walker coats the ends of sticks with a mixture of antimony sulfide, potassium chlorate, gum, and starch to produce "strike anywhere" matches.
1829	**Rocket steam locomotive** (George Stephenson): Stephenson builds the world's first railway line to use a steam locomotive.

Date	Invention/Milestone
1830	**Steam locomotive** (Peter Cooper): Cooper's four-wheel locomotive with a vertical steam boiler, the *Tom Thumb*, demonstrates the possibilities of steam locomotives and brings Cooper national fame. His other inventions and good management enable Cooper to become a leading industrialist and philanthropist.
1831	**Mechanical reaper** (Cyrus Hall McCormick): McCormick's reaper can harvest a field five times faster than earlier methods.
1831	**Alternating current (AC) generator** (Michael Faraday): Faraday constructs the world's first electric generator.
1832	**Electromagnetic induction** (Joseph Henry): Henry discovers that changing magnetic fields induces voltages in nearby conductors.
1835	**Colt revolver** (Samuel Colt): The Colt revolver becomes known as "one of the greatest advances of self-defense in all of human history."
1835	**Photography** (Nicéphore Niépce): Niépce codevelops photography with Louis-Jacques-Mandé Daguerre.
1837	**Steam hammer** (James Hall Nasmyth): Nasmyth develops the steam hammer, which he will use to build a pile driver in 1843.
1837	**Steel plow** (John Deere): Previously plows were made of cast iron and required frequent cleaning. Deere's plow is effective in reducing the amount of clogging farmers experienced when plowing the rich prairie soil.
1837	**Electric telegraph** (William Fothergill Cooke and Charles Wheatstone): Wheatstone and Cooke devise a system that uses five pointing needles to indicate alphabetic letters.
1838	**Fuel cell** (Christian Friedrich Schönbein): Schönbein's fuel cell might use hydrogen and oxygen and allow them to react, producing water and electricity. There are no moving parts, but the reactants must be continuously supplied.
1839	**Nitric acid battery** (Sir William Robert Grove): The Grove cell delivered twice the voltage of its more expensive rival, the Daniell cell.
1839	**Daguerreotype** (Louis Jacques Daguerre): Improving on the discoveries of Nicéphore Niépce, Daguerre develops the the first practical photographic process, the daguerreotype.
1839	**Vulcanized rubber** (Charles Goodyear): Adding sulfur and lead monoxide to rubber, Goodyear processes the batch at high temperature. The process, later called vulcanization, yields a stable material that does not melt in hot weather or crack in cold.
1840	**Electrical telegraph** (Samuel F. B. Morse): Others had already built telegraph systems, but Morse's system was superior and soon replaced all others.
1841	**Improved electric clock** (Alexander Bain): With John Barwise, Bain develops an electric clock with a pendulum driven by electric impulses to regulate the clock's accuracy.
1843	**Rotary printing press** (Richard March Hoe): Patented in 1847, the steam-powered rotary press is far faster than the flatbed press.
1843	**Multiple-effect vacuum evaporator** (Norbert Rillieux): Rillieux develops an efficient method for refining sugar using a stack of several pans of sugar syrup in a vacuum chamber, which allows boiling at a lower temperature.
1845	**Sewing machine** (Elias Howe): Howe develops a machine that can stitch straight, strong seams faster than those sewn by hand.
1845	**Suspension bridges** (John Augustus Roebling): A manufacturer of wire cable, Roebling wins a competition for an aqueduct over the Allegheny River and goes on to design other aqueducts and suspension bridges, culminating in the Brooklyn Bridge, which his son, Washington Augustus Roebling, completes in 1883.

Date	Invention/Milestone
1846	**Neptune discovered** (John Galle): German astronomer Galle observes a new planet, based on irregularities in the orbit of Uranus calculated the previous year by England's John Couch Adams and France's Urbain Le Verrier.
1847	**Telegraphy applications** (Werner Siemens): Siemens refines a telegraph in which a needle points to the alphabetic letter being sent.
1851	**Sewing machine** (Isaac Merrit Singer): Singer improves the sewing machine and successfully markets it to women for home use.
1851	**Foucault's pendulum** (Léon Foucault): Foucault's pendulum proves that Earth rotates.
1851	**Ophthalmoscope** (Hermann von Helmholtz): Helmholtz invents a device that can be used to examine the retina and the vitreous humor. In 1855, he will invent an ophthalmometer, an instrument that measures the curvature of the eye's lens.
1855	**Bessemer process** (Sir Henry Bessemer): Bessemer creates a converter that leads to a process for inexpensively mass-producing steel.
1855	**Bunsen burner** (Robert Wilhelm Bunsen): In 1859 Bunsen—along with Peter Desaga, an instrument maker, and Henry Roscoe, a student—develops a high-temperature laboratory burner, which he and Gustav Kirchhoff use to develop the spectroscope (1859).
1857	**Safety elevator** (Elisha Graves Otis): Otis's safety elevator automatically stops if the supporting cable breaks.
1858	**Internal combustion engine** (Étienne Lenoir): Lenoir's engine, along with his invention of the spark plug, sets the stage for the modern automobile.
1858	**Transatlantic cable** (Lord Kelvin): Kelvin helps design and install the under-ocean cables for telegraphy between North America and Europe, serving as a chief motivating force in getting the cable completed.
1859	**Signal flares** (Martha J. Coston): Coston's brilliant and long-lasting white, red, and green flares will be adopted by the navies of several nations.
1860	**Web rotary printing press** (William Bullock): Bullock's press has an automatic paper feeder, can print on both sides of the paper, and could cut the paper into sheets, and fold them.
1860	**Electric incandescent lamp** (Joseph Wilson Swan): Swan produces and patents an incandescent electric bulb; in 1880, two years after Edison's light bulb, Swan will produce a more practical bulb.
1861	**Machine gun** (Richard Gatling): Gatling develops the first machine gun, called the Gatling gun. It has six barrels that rotate into place as the operator turns a hand crank; the shells were automatically chambered and fired.
1861-1862	**USS *Monitor*** (John Ericsson): Ericsson develops the first practical ironclad ship, which will be used during the Civil War. He goes on to develop a torpedo boat that can fire a cannon from an underwater port.
1862	**Pasteurization** (Louis Pasteur): Pasteur's germ theory of disease leads him to develop a method of applying heat to milk products in order to kill harmful bacteria. He goes on to develop vaccines for rabies, anthrax, and chicken cholera (1867-1885).
1865	***Pioneer* (Pullman) sleeping car** (George Mortimer Pullman): Pullman began working on sleeping cars in 1858, but the *Pioneer* is a luxury car with an innovative folding upper berth to allow the passenger to sleep while traveling.
1867	**Dynamite** (Alfred Nobel): Nobel mixes clay with nitroglycerin in a one-to-three ratio to create dynamite (Nobel's Safety Powder), an explosive whose ignition can be controlled using Nobel's own blasting cap. He goes on to patent more than three hundred other inventions and devotes part of the fortune he gained from dynamite to establish and fund the Nobel Prizes.

DATE	INVENTION/MILESTONE
1867	**Steam velocipede motorcycle** (Sylvester Roper): Roper spent his lifetime making steam engines lighter and more powerful in order to make his motorized bicycles faster. His velocipede eventually reaches 60 miles (100 kilometers) per hour.
1867	**Flat-bottom paper bag machine** (Margaret E. Knight): Knight designs a machine that can manufacture flat-bottom paper bags, which can stand open for easy loading.
1867	**Baby formula** (Henri Nestlé): Nestlé combines cow's milk with wheat flour and sugar to produce a substitute for infants whose mothers cannot breast-feed.
1869	**Air brakes for trains** (George Westinghouse): In 1867, Westinghouse developed a signaling system for trains. The air brake makes it easier and safer to stop large, heavy, high-speed trains.
1869	**Periodic table of elements** (Dmitry Ivanovich Mendeleyev): The periodic table, which links chemical properties to atomic structure, will prove to be one of the great achievments of the human race.
1871	**Fireman's respirator** (John Tyndall): The respirator grows from Tyndall's studies of air pollution.
1872	**Blue jeans** (Levi Strauss): Miners tore their pockets when they stuffed too many ore samples in them. Strauss makes pants using heavy-duty material with riveted pocket corners so they will not tear out.
1872	**Burbank russet potato** (Luther Burbank): Burbank breeds all types of plants, using natural selection and grafting techniques to achieve new varieties. His Burbank potato, developed from a rare russet potato seed pod, grows better than other varieties.
1872	**Automatic lubricator** (Elijah McCoy): McCoy uses steam pressure to force oil to lubricate the pistons of steam engines.
1873	**QWERTY keyboard** (Christopher Latham Sholes): After patenting the first practical typewriter, Sholes develops the QWERTY keyboard, designed to slow the fastest typists, who otherwise jammed the keys. The basic QWERTY design remains the standard on most computer keyboards.
1873	**Barbed wire** (Joseph Glidden): Barbed-wire fences make farming and ranching of the Great Plains practical. Without effective fences, animals wandered off and crops were destroyed.
1874	**Medical nuclear magnetic resonance imaging** (Raymond Damadian): Damadian and others develop magnetic resonance imaging (MRI) for use in medicine.
1876	**Four-stroke internal combusion engine** (Nikolaus August Otto): In order to deliver more horsepower, Otto's engine compresses the air-fuel mixture. His previous engines operated near atmospheric pressure.
1876	**Telephone** (Elisha Gray): Gray files for a patent for the telephone the same day that Alexander Graham Bell does so. While the case is not clear-cut, and Gray fought with Bell for years over the patent rights, Bell is generally credited with the telephone's invention.
1876	**Ammonia-compressor refrigeration machine** (Carl von Linde): Breweries need refrigeration so they can brew year-round. Linde refines his ammonia-cycle refrigerator to make this possible.
1878	**Loose-contact carbon microphone** (David Edward Hughes): Hughes's carbon microphone advances telephone technology. In 1879, he will invent the induction balance, which will be used in metal detectors.
1878	**First practical light bulb** (Thomas Alva Edison): Twenty-two people have invented light bulbs before Edison and Joseph Swan, but they are impractical. Edison's is the first to be commercially viable. Eventually, Swan's company merges with Edison's.
1879	**Saccharin** (Ira Remsen): Remsen synthesizes a compound that is up to three hundred times sweeter than sugar; he also establishes the important *American Chemical Journal*, serving as its editor until 1915.
1880	**Milne seismograph** (John Milne): Milne invents the first modern seismograph for measuring earth tremors. He will come to be called the father of modern seismology.
1881	**Improved incandescent light bulb** (Lewis Howard Latimer): Latimer develops an improved way to manufacture and to attach carbon filaments in light bulbs.

DATE	INVENTION/MILESTONE
1882	**Induction motor** (Nikola Tesla): Tesla's theories and inventions make alternating current (AC) practical.
1882	**Two-cycle gasoline engine** (Gottlieb Daimler): Daimler builds a small, high-speed two-cycle gasoline engine. He will also build a successful motorcycle in 1885, and (with Wilhelm Maybach) an automobile in 1889.
1883	**Shoe-lasting machine** (Jan Ernst Matzeliger): The machine sews the upper part of the shoe to the sole and reduces the cost of shoes by 50 percent.
1884	**Fountain pen** (Lewis Waterman): The commonly told story is that Waterman was selling insurance and lost a large contract when his pen leaked all over it, prompting him to invent the leak-proof fountain pen.
1884	**Roll film** (George Eastman): Roll film replaces heavy plates, making photography both more accessible and more convenient. In 1888, Eastman and William Hall invent the Kodak camera. These developments open photography to the masses.
1884	**Steam turbine** (Charles Parsons): Designed for ships, Parsons's steam turbine is smaller, more efficient, and more durable than the steam engines in use.
1884	**Census tabulating machine** (Herman Hollerith): Hollerith's machine uses punched cards to tabulate 1890 census data. He goes on to found the company that later becomes International Business Machines (IBM).
1884	**Vector calculus** (Oliver Heaviside): Heaviside develops vector calculus to represent Maxwell's electromagnetic theory with only four equations instead of the usual twenty.
1885	**First gasoline-powered automobile** (Carl Benz): Benz not only manufactures the first gas-powered car but also is first to mass-produce automobiles.
1885	**Machine gun** (Hiram Stevens Maxim): Maxim patents a machine gun that can fire up to six hundred bullets per minute.
1886	**Dishwasher** (Josephine Garis Cochran): Like modern washers, Cochran's dishwasher cleans dishes with sprays of hot, soapy water and then air-dries them.
1886	**Linotype machine** (Ottmar Mergenthaler): Pressing keys on the machine's keyboard releases letter molds that drop into the current line. The lines are assembled into a page and then filled with molten lead.
1886	**Electric-traction system** (Frank J. Sprague): Sprague's motor can propel a tram up a steep hill without its slipping.
1886	**Gramophone** (Emile Berliner): A major contribution to the music recording industry, Berliner's gramophone uses flat record discs for recording sound. Berliner goes on to produce a helicopter prototype (1906-1923).
1886	**Coca-Cola** (John Stith Pemberton): Originally developed as a pain reliever less addictive than available opiates, the original Coca-Cola contains cocaine from cola leaves and caffeine from kola nuts. It achieves greater success as a beverage marketed where alcohol is prohibited.
1886	**Hall-Héroult electrolytic process** (Charles Martin Hall and Paul Héroult): The industrial production of aluminum from bauxite ore made aluminum widely available. Prior to the electrolytic process, aluminum was a precious metal with a value about equal to that of silver.
1886	**Yellow pages** (Reuben H. Donnelly): Yellow paper was used in 1883 when the printer ran out of white paper. Donnelly now purposely uses yellow paper for business listings.
1887	**Distortionless transmission lines** (Oliver Heaviside): Heaviside recommends that induction coils be added to telephone and telegraph lines to correct for distortion.
1887	**Radio transmitter and receiver** (Heinrich Hertz): Hertz will use these devices to discover radio waves and confirm that they are electromagnetic waves that travel at the speed of light; he also discovers the photoelectric effect.

DATE	INVENTION/MILESTONE
1887	**Synchronous multiplex railway telegraph** (Granville T. Woods): Woods patents a variation of the induction telegraph that allows messages to be sent between moving trains and between trains and railway stations. He will eventually obtain sixty patents on electrical and electromechanical devices, most of them related to railroads and communications.
1887	**Olds horseless carriage** (Ransom Eli Olds): Olds develops a three-wheel horseless carriage using a steam engine powered by a gasoline burner.
1888	**Cordite** (Sir James Dewar): Dewar, with Sir Frederick Abel, invents cordite, a smokeless gunpowder that is widely adopted for munitions.
1888	**Pneumatic rubber tire** (John Boyd Dunlop): Dunlop's pneumatic tires revolutionize the ride for cyclists and motorists.
1889	**Electric drill** (Arthur James Arnot): Arnot's drill is used to cut holes in rock and coal.
1889	**Bromine extraction** (Herbert Henry Dow): Dow's method for extracting bromine from brine enables bromine to be widely used in medicines and in photography.
1890	**Improved carbon electric arc** (Hertha Marks Ayrton): The carbon arc produces an intense light that is used in streetlights.
1890	**Pneumatic (air) hammer** (Charles B. King): A worker with a pneumatic hammer can break up a concrete slab many times faster than can a worker armed only with a sledgehammer.
1890	**Smokeless gunpowder** (Hudson Maxim): Hudson (perhaps with brother Hiram) develops a version of smokeless gunpowder that is adopted for modern firearms; he goes on to develop a smokeless cannon powder that will be used during World War I.
1891	**Rubber automobile tires** (André and Édouard Michelin): The Michelin brothers manufacture air-inflated tires for bicycles and later automobiles, which leads to a successful ad campaign, featuring the Michelin Man (Bibendum).
1891	**Carborundum** (Edward Goodrich Acheson): Attempting to create artificial diamonds, Acheson instead synthesizes silicon carbide, the second hardest substance known. He will develop an improved graphite-making process in 1896.
1892	**Calculator** (William Seward Burroughs): Burroughs builds the first practical key-operated calculator; it prints entries and results.
1892	**Dewar flask** (Sir James Dewar): Dewar invents the vacuum bottle, a vacuum-jacketed vessel for storing and maintaining the temperature of hot or cold liquids.
1893	**Color photography plate** (Gabriel Jonas Lippmann): Also known as the Lippmann plate for its inventor, the color photography plate uses interference patterns, rather than various colored dyes, to reproduce authentic color.
1893	**Alternating current calculations** (Charles Proteus Steinmetz): Steinmetz's calculations make it possible for engineers to determine alternating current reliably, without depending on trial and error, when designing a new motor.
1894	**Cereal flakes** (John Harvey Kellogg): Kellogg, a health reformer who advocates a diet of fruit, nuts, and whole grains, invents flaked breakfast cereal with the help of his brother, Will Keith Kellogg. In 1906, Kellogg establishes a company in Battlefield, Michigan, to manufacture his breakfast cereal.
1895	**Victrola phonographs** (Eldridge R. Johnson): Johnson develops a spring-driven motor for phonographs that provides the constant record speed necessary for good sound reproduction.
1895	**Streamline Aerocycle bicycle** (Ignaz Schwinn): Through hard work and dedication, Schwinn develops a bicycle that eventually makes his name synonymous with the best of bicycles.
1895	**Cinématographe** (Auguste and Louis Lumière): The Lumière brothers' combined motion-picture camera, printer, and projector helps establish the movie business. Using a very fine-grained silver-halide gelatin emulsion, they cut photographic exposure time down to about one minute.

Date	Invention/Milestone
1896	**Aerodromes** (Samuel Pierpont Langley): In 1896 Langley's "Aerodrome number 6," using a small gasoline engine, makes an unmanned flight of forty-eight hundred feet.
1896	**Four-wheel horseless carriage** (Ransom Eli Olds): Olds patents his internal combustion engine and applies it to his four-wheel horseless carriage, naming it the "automobile."
1896	**Wireless telegraph system** (Guglielmo Marconi): Marconi is the first to send wireless signals across the Atlantic Ocean, inaugurating a new era of telecommunications.
1896	**High-frequency generator and transformer** (Elihu Thomson): Thomson produces an electric air drill, which advances welding to improve the construction of new appliances and vehicles. He will also invent other electrical devices, including an improved X-ray tube.
1896	**X-ray tube** (Wilhelm Conrad Röntgen): After discovering X radiation, Röntgen mails an X-ray image of a hand wearing a ring and paves the way for the medical use of X-ray imaging—one of the most important discoveries ever made for medical science.
1897	**Oscilloscope** (Karl Ferdinand Braun): The oscilloscope is an invaluable device used to measure and display electronic waveforms.
1897	**Modern submarine** (John Philip Holland): Holland's submarine is the first to use a gasoline engine on the surface and an electric engine when submerged.
1897	**Diesel engine** (Rudolf Diesel): Diesel's internal combustion engine rivals the efficiency of the steam engine.
1897	**Jenny coupler** (Andrew Jackson Beard): Beard's automatic coupler connects the cars in a train without risking human life. The introduction of automatic couplings reduces coupling-related injuries by a factor of five.
1897	**Automobile components** (Alexander Winton): The Winton Motor Carriage Company is incorporated, and Winton begins manufacturing automobiles. His popular "reliability runs" help advertise automobiles to the American market. He will produce the first American diesel engine in 1913.
1897	**Escalator** (Charles Seeberger): Before Seeberger built the escalator in its now familiar form, it was a novelty ride at the Coney Island amusement park.
1897	**Electron discovered** (J. J. Thomson): Thomson uses an evacuated tube with a high voltage across electrodes sealed in the ends. Invisible particles (later named electrons) stream from one of the electrodes, and Thomson establishes the particles' properties.
1898	**Flashlight** (Conrad Hubert): Joshua Lionel Cowen suggested that a battery-powered light would look nice with a houseplant. Hubert combines three parts—a battery, a light bulb, and a metal tube—to produce a flashlight.
1898	**Mercury vapor lamp** (Peter Cooper Hewitt): Hewitts's mercury vapor lamp proves to be more efficient than incandescent lamps.
1899	**Alpha particle discovered** (Ernest Rutherford): Rutherford detects the emission of helium 4 nuclei (alpha particles) in the natural radiation from uranium.
1900	**Gamma ray discovered** (Paul Villard): Villard discovers gamma rays in the natural radiation from uranium. They resemble very high-energy X rays.
1900	**Dirigibles** (Ferdinand von Zeppelin): Zeppelin flies his airship three years before the Wright brothers' airplane.
1901	**String galvanometer (electrocardiograph)** (Willem Einthoven): Einthoven's device passes tiny currents from the heart through a silver-coated silicon fiber, causing the fiber to move. Recordings of this movement can show the heart's condition.
1901	**Acousticon hearing aid** (Miller Reese Hutchison): Hutchison invents a battery-powered hearing aid in hopes of helping a mute friend speak.
1901	**Vacuum cleaner** (H. Cecil Booth): Booth patents his vacuum cleaner, a machine that sucks in and traps dirt. Previous devices, less effective, had attempted to blow the dirt away.

DATE	INVENTION/MILESTONE
1902	**Airplane engine** (Charles E. Taylor): Taylor begins building engines for the Wright brothers' airplanes.
1902	**Air conditioner** (Willis Carrier): Whole-house air-conditioning becomes possible.
1902	**Lionel electric toy trains** (Joshua Lionel Cowen): Cowen publishes the first Lionel toy train catalog. Lionel miniature trains and train sets become favorite toys for many years, prized by collectors to this day.
1903	**Windshield wipers** (Mary Anderson): At first the driver operated the wiper with a lever from inside the car.
1903	**Safety razor with disposable blade** (King Camp Gillette): Gillette's razor used a disposable and relatively cheap blade, so there was no need to try to sharpen it.
1903	**Wright Flyer** (Wilbur and Orville Wright): The Wright Flyer is the first heavier-than-air machine to solve the problems of lift, propulsion, and steering for controlled flight.
1903	**Ultramicroscope** (Richard Zsigmondy): Zsigmondy builds the ultramicroscope to study colloids, mixtures in which particles of a substance are dispersed throughout another substance.
1903	**Space-traveling projectiles** (Konstantin Tsiolkovsky): Tsiolkovsky publishes "The Exploration of Cosmic Space by Means of Reaction-Propelled Apparatus," in which he includes an equation for calculating escape velocity (the speed required to propel an object beyond Earth's field of gravity). He is also recognized for the concept of rocket propulsion and for the wind tunnel.
1903	**Spinthariscope** (Sir William Crookes): Crookes invents a device that sparkles when it detects radiation. He also develops and experiments with the vacuum tube, allowing later physicists to identify alpha and beta particles and X rays in the radiation from uranium.
1903	**Crayola crayons** (Edwin Binney): With his cousin C. Harold Smith, Binney invents dustless chalk and crayons marketed under the trade name Crayolas.
1905	**Special relativity** (Albert Einstein): At the age of twenty-six, Einstein uses the constancy of the speed of light to explain motion, time, and space beyond Newtonian principles. During the same year, he publishes papers describing the photoelectric effect and Brownian motion.
1906	**Klaxon horn** (Miller Reese Hutchison): Hutchison files a patent application for the electric automobile horn.
1906	**Hair care products** (Madam C. J. Walker): Walker trains a successful sales force to go door-to-door and sell directly to women. Her saleswomen, beautifully dressed and coifed, are instructed to pamper their clients.
1906	**Broadcast radio** (Reginald Aubrey Fessenden): In broadcast radio, soundwave forms are added to a carrier wave and then broadcast. The carrier wave is subtracted at the receiver, leaving only the sound.
1907	**Sun valve** (Nils Gustaf Dalén): Dalén's device uses sunlight to activate a lighthouse beacon. His other inventions make automated acetylene beacons in lighthouses possible.
1908	**Cellophane** (Jacques Edwin Brandenberger): Brandenberger builds a machine to mass-produce cellophane, which he has earlier synthesized while unsuccessfully attempting to develop a stain-resistant cloth.
1908	**Helium liquefaction** (Heike Kamerlingh Onnes): Kamerlingh Onnes produces liquid helium at a temperature of about 4 kelvins. He will also discover superconductivity in several materials cooled to liquid helium temperature.
1908	**Electrostatic precipitator** (Frederick Gardner Cottrell): The electrostatic precipitator is invaluable for cleaning stack emissions.
1908	**"Tin Lizzie" (Model T) automobile** (Henry Ford): Ford's development of an affordable automobile, manufactured using his assembly-line production methods, revolutionizes the U.S. car industry.

DATE	INVENTION/MILESTONE
1908	**Vacuum cleaner** (James Murray Spangler): Spangler receives a patent on his electric sweeper, and his Electric Suction Sweeper Company eventually becomes the Hoover Company, the largest such company in the world.
1908	**Geiger-Müller tube** (Hans Geiger): Geiger invents a device, popularly called the Geiger counter, that is a reliable, portable radiation detector. Later his student, Walther Müller, helps improve the instrument.
1908	**Audion** (Lee de Forest): De Forest invents a vacuum tube used in sound amplification. In 1922 he will develop talking motion pictures, in which the sound track is imprinted on the film with the pictures, instead of on a record to be played with the film, leading to exact synchronization of sound and image.
1909	**Synthetic fertilizers** (Fritz Haber): Haber also invents the “Haber process” to synthesize ammonia on a small scale.
1909	**Maxim silencer** (Hiram Percy Maxim): The silencer reduces the noise from firing the Maxim machine gun.
1910	**Chlorinator** (Carl Rogers Darnall): Major Darnall builds a machine to add liquid chlorine to water to purify it for his troops. His method is still widely used today.
1910	**Neon lighting** (Georges Claude): Brightly glowing neon tubes revolutionize advertising displays.
1910	**Bakelite** (Leo Hendrik Baekeland): Bakelite is the first tough, durable plastic.
1911	**Gyrocompass** (Elmer Ambrose Sperry): Sperry receives a patent for a nonmagnetic compass that indicates true north.
1911	**Colt .45 automatic pistol** (John Moses Browning): Commonly called the Colt Model 1911, an improved version of the Colt Model 1900, the Colt .45 is the first autoloading pistol produced in America. Among Browning’s other inventions are the Winchester 94 lever-action rifle and the gas-operated Colt-Browning machine gun.
1911	**Ochoaplane, a plane with collapsible wings** (Victor Leaton Ochoa): Ochoa also developed an electricity-generating windmill.
1911	**Ductile tungsten** (William David Coolidge): He also invented the Coolidge tube, an improved X-ray-producing tube.
1911	**Atomic nucleus identified** (Ernest Rutherford): Rutherford discovered the nucleus by bombarding a thin gold foil with alpha particles. Some were deflected through large angles, showing that something small and hard was present.
1912	**Automatic traffic signal system** (Garrett Augustus Morgan): Morgan also invents a safety hood that served as a rudimentary gas mask.
1913	**Erector set** (Alfred C. Gilbert): Erector sets provide hands-on engineering experience for countless children.
1913	**Gyrostabilizer** (Elmer Ambrose Sperry): Sperry develops the gyrostabilizer, a device to control the roll, pitch, and yaw of a moving ship. He will go on to invent the flying bomb, which is guided by a gyrostabilizer and by radio control.
1913	**Zipper** (Gideon Sundback): While others had made zipper-like devices but had never successfully marketed them, Sundback designs a zipper in approximately its present form. He also invents a machine to make zippers.
1913	**Industrialization of the Haber process** (Carl Bosch): Bosch scales up Haber’s process for making ammonia to an industrial capacity. The process comes to be known as the Haber-Bosch process.
1913	**Improved electric light bulb** (Irving Langmuir): Langmuir fills his light bulb with a low-pressure inert gas to retard evaporation from the tungsten filament.
1913	**Bergius process** (Friedrich Bergius): Bergius develops a high-pressure, high-temperature process to produce liquid fuel from coal.

DATE	INVENTION/MILESTONE
1914	**Backless brassiere** (Caresse Crosby): The design of a new women's undergarment leads to the expansion of the U.S. brassiere industry. Caresse was originally a marketing name that Mary Phelps Jacob eventually adopted as her own.
1915	**General relativity** (Albert Einstein): Einstein refines his 1905 theory of relativity (now called special relativity) to describe the theory that states that uniform accelerations are almost indistinguishable from gravity. Einstein's theory provides the basis for physicists' best understanding of gravity and of the framework of the universe.
1915	**Jenny** (Glenn H. Curtiss): The Jenny becomes a widely used World War I biplane, and Curtis becomes a general manufacturer of airplanes and airplane engines.
1916	**By-products of sweet potatoes and peanuts** (George Washington Carver): In 1916 Carver publishes his famous bulletin on 105 ways to prepare peanuts.
1919	**Proton discovered** (Ernest Rutherford): After bombarding nitrogen gas with alpha particles (helium 4 nuclei), Rutherford observes that positive particles with a single charge are knocked loose. They are protons.
1920	**Microelectrode** (Ida H. Hyde): Hyde's electrode is small enough to pierce a single cell. Chemicals can also be very accurately deposited by the microprobe.
1923	**Improved telephone speaker** (Georg von Békésy): Békésy's studies of the human ear lead to an improved telephone earpiece. He will also construct a working model of the inner ear.
1923	**Quick freezing** (Clarence Birdseye): Birdseye's quick freezing process preserves food's flavor and texture better than previously used processes.
1924	**Coincidence method of particle detection** (Walther Bothe): Bothe's method proves invaluable in the use of gamma rays to discover nuclear energy levels.
1924	**Ultracentrifuge** (Theodor Svedberg): Svedberg's ultracentrifuge can separate isotopes, such as uranium 235 and uranium 238, from each other—a critical step in building the simplest kind of atomic bomb.
1926	**Automatic power loom** (Sakichi Toyoda): Toyoda's loom helps Japan catch up with the western Industrial Revolution.
1926	**Liquid-fueled rocket** (Robert H. Goddard): A solid-fueled rocket is either on or off, but a liquid-fueled rocket can be throttled up or back and can be shut off before all the fuel is expended.
1927	**Adiabatic demagnetization** (William Francis Giauque): Adiabatic demagnetization is part of a refrigeration cycle that, when used enough times, can chill a small sample to within a fraction of a kelvin above absolute zero.
1927	**All-electronic television** (Philo T. Farnsworth): Farnsworth transmits the first all-electronic television image using his newly developed camera vacuum tube, known as the image dissector. Previous systems combined electronics with mechanical scanners.
1928	**Sliced bread** (Otto F. Rohweddeer): Bread that came presliced was advertised as "the greatest forward step in the baking industry since bread was wrapped." Today the phrase "the greatest thing since sliced bread" is used to describe any innovation that has a broad, positive impact on daily life.
1928	**Link Trainer** (Edwin Albert Link): Link's flight simulator created realistic conditions in which to train pilots without the expense or risk of an actual airflight. Link also developed a submersible decompression chamber.
1929	**Iconoscope** (Vladimir Zworykin): Zworykin claims that he, not Philo Farnsworth. should be credited with the invention of television.
1929	**Dymaxion products** (R. Buckminster Fuller): Fuller's "Dymaxion" products feature an energy-efficient house using prefabricated, easily-shipped parts.

DATE	INVENTION/MILESTONE
1929	**Strobe light** (Harold E. Edgerton): Edgerton's strobe is used as a flash bulb. He pioneers the development of high-speed photography.
1929-1936	**Cyclotron** (Ernest Orlando Lawrence and M. Stanley Livingston): Lawrence and Livingston are studying particle accelerators and develop the cyclotron, which consists of a vacuum tank between the poles of a large magnet. Alternating electric fields inside the tank can accelerate charged particles to high speeds. The cyclotron is used to probe the atomic nucleus or to make new isotopes of an element, including those used in medicine.
1930	**Schmidt telescope** (Bernhard Voldemar Schmidt): Schmidt's telescope uses a spherical main mirror and a correcting lens at the front of the scope. It can photograph large fields with little distortion.
1930	**Freon refrigeration and air-conditioning** (Charles F. Kettering): After inventing an electric starter in 1912 and the Kettering Aerial Torpedo in 1918 (the world's first cruise missile), he and Thomas Midgley, Jr., use Freon gas in their cooling technology. (Freon will later be banned because of the effects of chlorofluorocarbons on Earth's ozone layer.)
1930	**Scotch tape** (Richard G. Drew): After inventing masking tape, Drew invents the first waterproof, see-through, pressure-sensitive tape that also acted as a barrier to moisture.
1930	**Pluto discovered** (Clyde Tombaugh): Tombaugh observes a body one-fifth the mass of Earth's moon. Pluto comes to be regarded as the ninth planet of the solar system, but in 2006 it is reclassified as one of the largest known Kuiper Belt objects, a dwarf planet.
1930	**Synthetic rubber** (Wallace Hume Carothers): Carothers synthesizes rubber and goes on to develop nylon in 1935. His work professionalizes polymer chemistry as a scientific field.
1930	**Military and commercial aircraft** (Andrei Nikolayevich Tupolev): Tupolev emerges as one of the world's leading designers of military and civilian aircraft. His aircraft set nearly eighty world records.
1931	**Radio astronomy** (Karl G. Jansky): One of the founders of the field of radio astronomy, Janksy detects radio static coming from the Milky Way's center.
1931	**Electric razor** (Jacob Schick): Schick introduces his first electric razor, which allows dry shaving. It has a magazine of blades held in the handle.
1932	**Neutron discovered** (James Chadwick): Chadwick detects the neutron, an atomic particle with no charge and a mass only slightly greater than that of a proton. Except for hydrogen 1, the atomic nuclei of all elements consist of neutrons and protons.
1932	**Positron discovered** (Carl D. Anderson): Anderson discovers the positron, a positive electron and an element of antimatter.
1932	**Cockroft-Walton accelerator** (John Douglas Cockcroft and Ernest Thomas Sinton Walton): the Cockcroft-Walton accelerator is used to fling charged particles at atomic nuclei in order to investigate their properties.
1932	**Duplicating device for typewriters** (Beulah Louise Henry): Henry's invention uses three sheets of paper and three ribbons to produce copies of a document as it is typewritten. Henry also develops children's toys—for example, a doll whose eye color can be changed.
1932	**Richter scale** (Charles Francis Richter): Richter develops a scale to describe the magnitude of earthquakes, still used today.
1932	**Phillips-head screw** (Henry M. Phillips): The phillips-head screw has an X-shaped slot in the head and can withstand the torque of a machine-driven screwdriver, which is greater than the torque that can be withstood by the conventional screw.
1933	**Nuclear chain reaction** (Leo Szilard): Szilard conceives the idea of a nuclear chain reaction. He becomes a key figure in the Manhattan Project, which eventually builds the atomic bomb.
1933	**Magnetic tape recorder** (Semi Joseph Begun): Begun builds the first tape recorder, a dictating machine using wire for magnetic recording. He also develops the first steel tape recorder for mobile radio broadcasting and leads research into telecommunications and underwater acoustics.

DATE	INVENTION/MILESTONE
1933	**Electron microscope** (Ernst Ruska): Ruska makes use of the wavelengths of electrons—shorter than those of visible light—to build a microscope that can image details at the subatomic level.
1934	**Langmuir-Blodgett films** (Katharine Burr Blodgett): A thin Langmuir-Blodgett film deposited on glass can make it nearly nonreflective.
1935	**Diatometer** (Ruth Patrick): Patrick's diatometer is a device placed in the water to collect diatoms and allow them to grow. The number of diatoms is sensitive to water pollution.
1935	**Frequency modulation** (Edwin H. Armstrong): Armstrong exploits the fact that, since there are no natural souces of frequency modulation (FM), FM broadcasts are static-free.
1935	**Kodachrome color film** (Leopold Mannes and Leopold Godowsky, Jr.): Godowsky and Mannes invent Kodachrome, a color film that is easy to use and produces vibrant colors. (With the digital revolution of the late twentieth century, production of Kodachrome is finally retired in 2009.)
1935	**Mobile refrigeration** (Frederick McKinley Jones): Mobile refrigeration enables the shipping of heat-sensitive products and compounds, from blood to frozen food.
1935	**Physostigmine and cortisone** (Percy Lavon Julian): Julian synthesizes physostigmine, used to treat glaucoma, and cortisone, used for arthritis. He will hold more than 130 patents and will become the first African American chemist inducted into the National Academy of Sciences.
1935	**Fallingwater** (Frank Lloyd Wright): Wright designs and builds a showcase house blending its form with its surroundings. One of the greatest architects of the twentieth century, he will produce many architectural innovations in structure, materials, and design.
1935	**Radar-based air defense system** (Sir Robert Alexander Watson-Watt): Watson-Watt's technical developments and his efforts as an administrator will be so important to the development of radar that he will be called the "father of radar."
1936	**Pentothal** (Ernest Volwiler and Donalee Tabern): Pentothal is a fast-acting intravenous anesthetic.
1936	**Field-emission microscope** (Erwin Wilhelm Müller): Müller completes his dissertation, "The Dependence of Field Electron Emission on Work Function," and goes on to develop the field-emission microscope, which can resolve surface features as small as 2 nanometers.
1937	**Muon discovered** (Seth Neddermeyer): Neddermeyer, working with Carl Anderson, J. C. Street, and E. C. Stevenson, discovers the muon (a particle similar to a heavy electron) while examining cosmic-ray tracks in a cloud chamber.
1937	**Model K computer** (George Stibitz): The model K, an early electronic computer, employs Boolean logic.
1937	**X-ray crystallography** (Dorothy Crowfoot Hodgkin): Hodgkin uses X-ray crystallography to reveal the structure of molecules.
1937	**Concepts of digital circuits and information theory** (Claude Elwood Shannon): Shannon's most important contributions were electronic switching and using information theory to discover the basic requirements for data transmission.
1938	**Teflon** (Roy J. Plunkett): Plunkett accidentally synthesizes polytetrafluoroethylene (PTFE), now commmonly known as Teflon, while researching chlorofluorocarbon refrigerants.
1938	**Walkie-talkie** (Alfred J. Gross): Gross's portable, two-way radio allows the user to move around while sending messages without remaining tied to a bulky transmitter. Gross invents a pager in 1949 and a radio tuner in 1950 that automatically follows the drift in carrier frequency due to movement of a sender or receiver.
1938	**Xerography** (Chester F. Carlson): Xerography uses electrostatic charges to attract toner particles to make an image on plain paper. A hot wire then fuses the toner in place.
1938	**Electron microscope** (James Hillier and Albert Prebus): Adapting the work of German physicists, Hillier and Prebus develop a prototype of the electron microscope; and in 1940 Hillier produces the first commercial electron microscope available in the United States.

DATE	INVENTION/MILESTONE
1939	**Helicopter** (Igor Sikorsky): Sikorsky, formerly the chief construction engineer and test pilot for the first four-engine aircraft, tests his helicopter, the Vought-Sikorsky 300, which after improvements will emerge as the world's first working helicopter.
1939	**Jet engine** (Hans Joachim Pabst von Ohain): The first jet-powered aircraft flies in 1939, while the first jet fighter will fly in 1941.
1939	**Atanasoff-Berry Computer** (Clifford Berry and John Vincent Atanasoff): The ABC, the world's first electronic digital computer, uses binary numbers and electronic switching, but it is not programmable.
1940	**Blood bank** (Charles Richard Drew): Drew establishes blood banks for World War II soldiers.
1940	**Audio oscillator** (William Redington Hewlett): Hewlett invents the audio oscillator, a device that creates one frequency (pure tone) at a time. It is the first successful product of his Hewlett-Packard Company.
1940	**Color television** (Peter Carl Goldmark): Goldmark produces a system for transmitting and receiving color-television images using synchronized rotating filter wheels on the camera and on the receiver set.
1940	**Thompson submachine gun** (John T. Thompson): Thompson works with Theodore Eickhoff and Oscar Payne to invent the American version of the submachine gun.
1940	**Paintball gun** (Charles and Evan Nelson): The gun and paint capsules, invented to mark hard-to-reach trees in the forest, are eventually used for the game of paintball (1981), in which people shoot each other with paint.
1940	**Antibiotics** (Selman Abraham Waksman): Waksman, through study of soil organisms, finds sources for the world's first antibiotics, including streptomycin and actinomycin.
1940	**Plutonium** (Glenn Theodore Seaborg): Seaborg synthesizes one of the first transuranium elements, plutonium. He becomes one of the leading figures in the Manhattan Project, which will build the atomic bomb. While he and others urged the demonstration of the bomb as a deterrent, rather than its use on the Japanese civilian population, the latter course was taken.
1940's	**Solar technology** (Maria Telkes): Telkes develops the solar oven and solar stills to produce drinking water from ocean water.
1941	**Jet engine** (Sir Frank Whittle): Whittle develops the jet engine independent of Hans Joachim Pabst von Ohain in Germany. After World War II, they meet and become good friends.
1941	**Solid-body electric guitar** (Les Paul): Paul's guitar lays the foundation for rock music. He also develops multitrack recording in 1948.
1941	**Velcro** (Georges de Mestral): Burrs sticking to his dog's fur give Mestral the idea for Velcro, which he perfects in 1948.
1941	**Z3 programmable computer** (Konrad Zuse): Zuse and his colleagues complete the first general-purpose, programmable computer, the Z3, in December. In 1950, Zuse will sell a Z4 computer—the only working computer in Europe.
1942	**Superglue** (Harry Coover and Fred Joyner): After developing superglue (cyanoacrylate), Coover rejects it as too sticky for a 1942 project. Coover and Joyner rediscover superglue in 1951, when Coover recognizes it as a marketable product.
1942	**Synthetic vitamins** (Max Tishler): After synthesizing several vitamins during the 1930's, Tischler and his team develop the antibiotic sulfaquinoxaline to treat coccidiosis. He also develops fermentation processes to produce streptomycin and penicillin.
1942	**Controlled nuclear chain reaction** (Enrico Fermi): In 1926, Fermi helped develop Fermi-Dirac statistics, which describe the quantum behavior of groups of electrons, protons, or neutrons. He now produces the first sustained nuclear chain reaction.

Date	Invention/Milestone
1942	**Aqua-Lung** (Jacques-Yves Cousteau and Émile Gagnon): The Aqua-Lung delivers air at ambient pressure and vents used air to the surroundings.
1944	**V-2 rocket** (Wernher von Braun): Working for the German government during World War II, von Braun and other rocket scientists develop the V-2 rocket, the first long-range military missile and first suborbital missile. Arrested for making anti-Nazi comments, he later emigrates to the United States, where he leads the team that produces the Jupiter-C missile and launch vehicles such as the Saturn V, which help make the U.S. space program possible.
1944	**Phased array radar antennas** (Luis W. Alvarez): Alvarez's phased array sweeps a beam across the sky by turning hundreds of small antennas on and off and not by moving a radar dish.
1945	**Atomic bomb** (J. Robert Oppenheimer): Oppenheimer, the scientific leader of the Manhattan Project, heads the team that builds the atomic bomb. On the side of military use of the bomb to end World War II quickly, Oppenheimer saw this come to pass on August 6, 1945, when the bomb was dropped over Hiroshima, Japan, killing and maiming 150,000 people; a similar number of casualties ensued in Nagasaki on August 9, when the second bomb was dropped. Japan surrendered on August 14.
1945	**Automatic Computing Engine** (Alan Mathison Turing): While the ACE was never fully built, it was one of the first stored-program computers.
1945	**Dialysis machine** (Willem Johan Kolff): Kolff designs the first artificial kidney, a machine that cleans the blood of patients in renal failure, and refuses to patent it. He will construct the artificial lung in 1955.
1945	**Electronic Sackbut** (Hugh Le Caine): Caine builds the first music synthesizer, joined by the Special Purpose Tape Recorder in 1954, which could simultaneously change the playback speed of several recording tracks.
1945	**Radioimmunoassay** (Rosalyn Yalow): RIA required only a drop of blood (rather than the tens of milliliters previously required) to find trace amounts of substances.
1945	**Microwave oven** (Percy L. Spencer): The microwave oven grew out of the microwave generator, the magnetron tube, becoming more affordable.
1945	**ENIAC computer** (John William Mauchly and John Presper Eckert): The Electronic Numerical Integrator and Computer, ENIAC, is the first general-purpose, programmable, electronic computer. (The Z3, developed independently by Konrad Zuse independently from 1939 to 1941 in Nazi Germany, did not fully exploit electronic components.) Built to calculate artillery firing tables, ENIAC is used in calculations for the hydrogen bomb.
1946	**Tupperware** (Earl S. Tupper): Tupperware exploits plastics technology to develop a line of plastic containers that he markets at home parties starting in 1948.
1946	**Carbon-14 dating** (Willard F. Libby): Libby uses the half-life of carbon 14 to develop a reliable means of dating ancient remains. Radiocarbon dating has proven to be invaluable to archaeologists.
1946	**Magnetic tape recording** (Marvin Camras): Camras develops a magnetic tape recording process that will be adapted for use in electronic media, including music and motion-picture sound recording, audio and videocassettes, floppy disks, and credit card magnetic strips. For many years his method is the primary way to record and store sound, video, and digital data.
1946-1947	**Audiometer** (Georg von Békésy): Békésy invents a pure-tone audiometer that patients themselves can control to measure the sensitivity of their own hearing.
1947	**Transistor** (John Bardeen, Walter H. Brattain, and William Shockley): Hoping to build a solid-state amplifier, the team of Bardeen, Shockley, and Brattain discover the transistor, which replaces the vacuum tube in electronics. Bardeen is later part of the group that develops the theory of superconductivity.
1948	**Holography** (Dennis Gabor): Gabor publishes his initial results working with holograms in *Nature*. Holograms became much more spectacular after the invention of the laser.

DATE	INVENTION/MILESTONE
1948	**Gamma-ray pinhole camera** (Roscoe Koontz): Working to make nuclear reactors safer, Koontz invents the gamma-ray pinhole camera. The pinhole should act like a lens and form an image of the gamma source.
1948	**Instant photography** (Edwin Herbert Land): Land develops the simple process to make sheets of polarizing material. He perfects the Polaroid camera in 1972.
1948	**Synthetic penicillin** (John C. Sheehan): Sheehan develops the first total synthesis of penicillin, making this important antibiotic widely available.
1948	**Long-playing record** (Peter Carl Goldmark): Goldmark demonstrates the LP playing the cello with CBS musicians. The musical *South Pacific* is recorded in LP format and boosts sales, making the LP the dominant form of recorded sound for the next four decades.
1949	**Magnetic core memory** (Jay Wright Forrester): Core memory is used from the early 1950's to the early 1970's.
1950	**Purinethol** (Gertrude Belle Elion): Elion develops the first effective treatment for childhood leukemia, 6-mercaptopurine (Purinethol). Elion later discovers azathioprine (Imuran), an immunosuppressive agent used for organ transplants.
1950	**Artificial pacemaker** (John Alexander Hopps): Hopps develops a device to regulate the beating of the heart to treat patients with erratic heartbeats. By 1957, the device is small enough to be implanted.
1950	**Planotron** (Pyotr Leonidovich Kapitsa): Kapitsa invents a magnetron tube for generating microwaves. He becomes a corecipient of the Nobel Prize for Physics in 1978 for discovering superfluidity in liquid helium.
1951	**Field-emission microscope** (Erwin Wilhelm Müller): Müller develops the field-ion microscope, followed by an atom-probe field-ion microscope in 1963, which can detect individual atoms.
1951	**The Pill** (Carl Djerassi): The birth-control pill, which becomes the world's most popular and is possibly the most widely used contraceptive, revolutionizes not only medicine but also gender relations and women's status in society. Its prolonged use is later revealed to have health consequences.
1951	**Maser** (Charles Hard Townes): The maser (microwave amplification by stimulated emission of radiation) is a "laser" for microwaves. Discovered later, the "laser" patterned its name on the acronym "maser."
1951	**Fiber-optic endoscope (fibroscope)** (Harold Hopkins): Hopkins fastened together a flexible bundle of optical fibers that could convey an image. One end of the bundle could be inserted into a patient's throat, and the physician could inspect the esophagus.
1952	**Improved electrical resistor** (Otis Boykin): Boykin's resistor had improved precision, and its high frequency characteristics were better than those of previous resistors.
1952	**Photovoltaic cell** (Gerald Pearson): The photovoltaic cell converts sunlight into electricity.
1952	**COBOL** (Grace Murray Hopper): Hopper invents the compiler, an intermediate program that translates English-language instructions into computer language, followed in 1959 by Common Business Oriented Language (COBOL), the first computer programming language to translate commands used by programmers into the machine language the computer understands.
1952	**Bubble chamber** (Donald A. Glaser): In a bubble chamber, bubbles form along paths taken by subatomic particles as they interact, and the bubble trails allow scientists to deduce what happened.
1953	**Medical ultrasonography** (Inge Edler and Carl H. Hertz): Edler and Hertz adapt an ultrasound probe used in materials testing in a shipyard for use on a patient. Their technology makes possible echograms of the heart and of the brain.
1953	**Inertial navigation systems** (Charles Stark Draper): Draper's INS system is designed to determine the current position of a ship or plane based on the initial location and acceleration.

Date	Invention/Milestone
1954	**Geodesic dome** (R. Buckminster Fuller): After developing the geodesic dome, Fuller patents the structure, an energy-efficient house using prefabricated, easily-shipped parts.
1954	**Synthetic diamond** (H. Tracy Hall): Hall synthesizes diamonds using a high-pressure, high-temperature belt apparatus that can generate 120,000 atmospheres of pressure and sustain a temperature of 1,800° Celsius in a working volume of about 0.1 cubic centimeter.
1954	**Hydrogen bomb** (Edward Teller): The first hydrogen bomb, designed by Teller, is tested at the Bikini Atoll in the Pacific Ocean.
1954	**Silicon solar cells** (Calvin Fuller): Silicon solar cells have proven to be among the most efficient and least expensive solar cells.
1954	**Machine vision** (Jerome H. Lemelson): Machine vision allows a computer to move and measure products and to inspect them for quality control.
1954	**Atomic absorption spectroscopy** (Sir Alan Walsh): Atomic absorption spectroscopy is used to identify and quantify the presence of elements in a sample.
1955	**Color television's RGB system** (Ernst Alexanderson): The RGB system uses three image tubes to scan scenes through colored filters and three electron guns in the picture tube to reconstruct scenes.
1955	**Pulse transfer controlling device** (An Wang): The device allows magnetic core memory to be written or read without mechanical motion and is therefore very rapid.
1955	**Hovercraft** (Sir Christopher Cockerell): Cockerell files a patent for his hovercraft, an amphibious vehicle. He earlier invented several important electronic devices, including a radio direction finder for bombers in World War II.
1955	**Polio vaccine** (Jonas Salk): Salk's polio vaccine, which uses the killed virus, saves lives and improves the quality of life for millions afflicted by polio.
1955	**Floppy disk and floppy disk drive** (Alan Shugart): Working at the San Jose offices of International Business Machines (IBM), Shugart develops the disk drive, followed by "floppy" disks to provide a relatively fast way to permanently store programs and data.
1956	**Scotchgard** (Patsy O'Connell Sherman): Sherman develops a stain repellent for fabrics that is trademarked as Scotchgard.
1956	**Liquid Paper** (Bette Nesmith Graham): Graham markets her "Mistake Out" fluid for concealing typographical errors.
1956	**Videotape recorder** (Charles P. Ginsburg): The video recorder allows programs to be shown later, to provide instant replays in sports, and to make a permanent record of a program.
1956	**Dipstick blood sugar test** (Helen M. Free): Free and her husband Alfred coinvent a self-administered urinalysis test that allows diabetics to monitor their sugar levels and to adjust their medications accordingly.
1956	**Ovonic switch** (Stanford Ovshinsky): Ovshinsky invents a solid-state, thin film switch meant to mimic the actions of neurons.
1957	**Laser** (Gordon Gould, Charles Hard Townes, Arthur L. Schawlow, Theodore Harold Maiman): Having conducted research on using light to excite thallium atoms, Gould tries to get funds and approval to build the first laser, but he fails. Townes (inventor of the maser) and Schawlow of Bell Laboratories will first describe the laser, and Maiman will first succeed in building a small optical maser. Gould coins the term "laser," which stands for "light amplification by stimulated emission of radiation."
1957	**Wankel rotary engine** (Felix Wankel): Having fewer moving parts, the Wankel rotary engine ought to be sturdier and perhaps more efficient than the common reciprocating engine.
1958	**Integrated circuit** (Robert Norton Noyce and Jack St. Clair Kilby): The microchip, independently discovered by Noyce and Kilby, proves to be the breakthrough that allows the miniaturization of electronic circuits and paves the way for the digital revolution.

DATE	INVENTION/MILESTONE
1960	**Echo satellite** (John R. Pierce): The first passive-relay telecommunications satellite, Echo, reflected signals. The signals, received from one point on Earth, "bounce" off the spherical satellite and are reflected back down to another, far distant, point on Earth.
1960	**Ruby laser** (Theodore Harold Maiman): Maiman produces a ruby laser, the world's first visible light laser.
1960	**Helium-neon gas laser** (Ali Javan): Javan produces the world's second visible light laser.
1960	**Automatic letter-sorting machine** (Jacob Rabinow): Rabinow's machine greatly increases the speed and efficiency of mail delivery in the United States. He also invented an optical character recognition scanner.
1961	**Audio-animatronics** (Walt Disney): Disney established WED, a research and development unit that developed the inventions he needed for his various enterprises. WED produced the audio-animatronic robotic figures that populated Disneyland, the 1964-1965 New York World's Fair, films, and other attractions. Audio-animatronics enabled robotic characters to speak or sing as well as move.
1962	**Quasar 3C 273** (Maarten Schmidt): Schmidt shows that this quasar is very distant and hence very bright. Further research shows quasars to be young galaxies with active, supermassive black holes at their centers.
1962	**Soft contact lenses** (Otto Wichterle): Wichterle's soft contacts can be worn longer with less discomfort than with hard contact lenses.
1962	**Continuously operating ruby laser** (Willard S. Boyle and Don Nelson): The invention relies on an arc lamp shining continuously (rather than the flash lamp used by Theodore Harold Maiman in 1960).
1962	**Light-emitting diode** (Nick Holonyak, Jr.): Holonyak makes the first visible-spectrum diode laser, which produces red laser light but also stops lasing yet remains a useful light source. Holonyak has invented the red light-emitting diode (LED), the first operating alloy device—the "ultimate lamp."
1962	**Telstar satellite** (John R. Pierce): The first satellite to rebroadcast signals goes into operation, revolutionizing telecommunications.
1963	**Learjet** (Bill Lear): The Learjet, a small eight-passenger jet with a top speed of 560 miles (900 kilometers) per hour, can shuttle VIPs to meetings and other engagements.
1963	**6600 computer** (Seymour Cray): The 6600 was the first of a long line of Cray "supercomputers."
1963	**Artificial heart** (Paul Winchell): Winchell receives a patent (later donated to the University of Utah's Institute for Biomedical Engineering) for an artifical heart that purportedly became the model for the successful Jarvik-7.
1964	**Moog synthesizer** (Robert Moog): The Moog synthesizer uses electronics to create and combine musical sounds.
1964	**Three-dimensional holography** (Emmett Leith): Leith and Juris Upatnieks present the first three-dimensional hologram at the Optical Society of America conference. The hologram must be viewed with a reference laser. The hologram of an object can then be viewed from different angles, as if the object were really present.
1964	**Cosmic background radiation** (Arno Penzias and Robert Wilson): Penzias and Wilson detect the cosmic background radiation, which corresponds to that that would be radiated by a body at 2.725 kelvins. It is thought that it is greatly redshifted primordial fireball radiation left over from the big bang.
1965	**Minicomputer** (Ken Olsen): Perhaps the first true minicomputer, the PDP-8, is released by Digital Equipment Corporation. Founder Olsen makes computers affordable for small businesses.
1966	**Gamma-electric cell** (Henry Thomas Sampson): Sampson works with George H. Miley to produce the gamma-electric cell, which converts the energy of gamma rays into electrical energy.

DATE	INVENTION/MILESTONE
1966	**Handheld calculator** (Jack St. Clair Kilby): Working for Texas Instruments, Kilby does for the adding machine what the transistor had done for the radio, inventing a handheld calculator that retails at $150 and becomes an instant commercial success.
1967	**Electrogasdynamic method and apparatus** (Meredith C. Gourdine): Gourdine develops electrogasdynamics, which involves the production of electricity from the conversion of kinetic energy in a moving, ionized gas.
1967	**Pulsars** (Jocelyn Bell and Antony Hewish): Pulsars, rapidly rotating neutron stars, are discovered.
1968	**Practical liquid crystal displays** (James Fergason): Fergason develops an LCD screen that has good visual contrast, is durable, and uses little electricity.
1969	**Charge-coupled device** (Willard S. Boyle and George E. Smith): Boyle and Smith develop the charge-coupled device, the basis for digital imaging.
1970	**Optical fiber** (Robert Maurer and others): Maurer, joined by Donald Keck, Peter Schultz, and Frank Zimar, produces an optical fiber that can be used for communication.
1970	**Compact disc** (James Russell): The CD revolutionizes the way digital media is stored.
1971	**Electronic switching system for telecommunications** (Erna Schneider Hoover): Hoover's system prioritizes telephone calls and fixes an efficient order to answer them.
1971	**Intel microprocessors** (Federico Faggin): Intel builds the world's first microprocessor chip.
1971	**Lithium-iodide battery** (Wilson Greatbatch): Greatbatch produces an artificial pacemaker. Although there are other pacemakers, Greatbatch's proves superior.
1971	**Touch screen** (Sam Hurst): Hurst's touch screen can detect if it has been touched and where it was touched.
1971	**Microprocessor** (Ted Hoff): The computer's central processing unit (CPU) is reduced to the size of a postage stamp.
1971	**Computerized axial tomography** (Godfrey Newbold Hounsfield): In London, doctors performed the first CAT scan of a living patient and detect a brain tumor. In a CAT (or CT) scan, X rays are taken of a body like slices in a loaf of bread. A computer then assembles these slices into a detail-laden three-dimensional image.
1972	**Cell encapsulation** (Taylor Gunjin Wang): Wang develops ways to encapsulate beneficial cells and introduce them into a body without triggering the immune system.
1972	***Pong* video game** (Nolan K. Bushnell and Ted Dabney): Bushnell and Dabney register the name of their new computer company, Atari, and issue *Pong* shortly thereafter, marking the rise of the video game industry.
1972	**Far-Ultraviolet Camera** (George R. Carruthers): The Carruthers-designed camera is used on the Apollo 16 mission.
1972	**First recombinant DNA organism** (Stanley Norman Cohen, Paul Berg, and Herbert Boyer): The methods to combine and transplant genes are discovered when this team successfully clones and expresses the human insulin gene in the *Escherichia coli*.
1973	**Automated teller machine** (Don Wetzel): Wetzel receives a patent for his ATM. To make it a success, he shows banks how to generate a group of clients who would use the ATM.
1973	**Automatic computerized transverse axial (ACTA) whole-body CT scanner** (Robert Steven Ledley): The first whole-body CT scanner is operational. Ledley goes on to spend much of his career promoting the use of electronics and computers in biomedical research.
1973	**Packet network interconnection protocols TCP/IP** (Vinton Gray Cerf and Bob Kahn): Cerf and Kahn develop Transmission Control Protocol/Internet Protocol (TCP/IP), protocols that enable computers to communicate with one another.
1974	**Kevlar** (Stephanie Kwolek): Kwolek receives a patent for the fiber Kevlar. Bullet-resistant Kevlar vests go on sale only one year later.

Date	Invention/Milestone
1975	**Ethernet** (Robert Metcalfe and David Boggs): Metcalfe and Boggs invent the Ethernet, a system of software, protocols, and hardware allowing instantaneous communication between computer terminals in a local area.
1976	**Kurzweil reading machine** (Ray Kurzweil): Kurzweil develops an optical character reader able to read most fonts.
1976	**Apple computer** (Steve Jobs): Jobs cofounds Apple Computer with Steve Wozniak.
1976	**Personal computer** (Steve Wozniak): Wozniak develops the Apple II, the best-selling computer of the 1970's and early 1980's.
1976	**Jarvik-7 artificial heart** (Robert Jarvik): The Jarvik-7 allows a calf to live 268 days with the artificial heart. Jarvik combined ideas from several other workers to produce the Jarvik-7.
1976	**Microsoft Corporation** (Bill Gates): Gates, along with Paul Allen, founds Microsoft, a software company. Gates will remain head of Microsoft for twenty-five years.
1977	**Gossamer Condor** (Paul MacCready): MacCready designs the Gossamer Condor, which enables human-powered flight.
1977	**Global Positioning System** (Ivan A. Getting): The first GPS satellite is launched, designed to support a navigational system that uses satellites to pinpoint the location of a radio receiver on Earth's surface.
1978	**Charon discovered** (James Christy): Charon is discovered as an apparent bulge on a fuzzy picture of Pluto. Its mass is about 12 percent that of Pluto.
1978	**Smart gels** (Toyoichi Tanaka): Tanaka discovers and works with "smart gels," polymer gels that can expand a thousandfold, change color, or contract when stimulated by minor changes in temperature, magnetism, light, or electricity. This capacity makes them useful in a broad range of applications.
1979	**In-line roller skates** (Scott Olson and Brennan Olson): After finding some antique in-line skates, the Olson brothers begin experimenting with modern materials, creating modern Rollerblades.
1980	**Alkaline battery** (Lewis Urry): Eveready markets alkaline batteries under the trade name Energizer. Urry's alkaline battery lasts longer than its predecessor, the carbon-zinc battery.
1981	**Scanning tunneling microscope** (Heinrich Rohrer and Gerd Binnig): The scanning tunneling microscope shows surfaces at the atomic level.
1981	**Ablative photodecomposition** (Rangaswamy Srinivasan): Srinivasan's research on ablative photodecomposition leads to multiple applications, including laser-assisted in situ keratomileusis (LASIK) surgery, which shapes the cornea to correct vision problems.
1981	**Improvements in laser spectroscopy** (Arthur L. Schawlow and Nicolaas Bloembergen): Schawlow shares the Nobel Prize in Physics with Bloembergen for their work on laser spectroscopy. While most of Schawlow's inventions involved lasers, he also did research in superconductivity and nuclear resonance.
1983	**Cell phone** (Martin Cooper): The first mobile (wireless) phone, the DynaTAC 8000X, receives approval by the Federal Communications Commission, heralding an age of wireless communication.
1983	**Polymerase chain reaction** (Kary B. Mullis): While driving to his cottage in Mendocino, California, Mullis develops the idea for the polymerase chain reaction (PCR). PCR will be used to amplify a DNA segment many times, leading to a revolution in recombinant DNA technology and a 1993 Nobel Prize in Chemistry for Mullis.
1984	**AIDS blood test** (Robert Charles Gallo): Gallo and his colleagues identify the virus HTLV-3/LAV (later renamed human immunodeficiency virus, or HIV) as the cause of acquired immunodeficiency syndrome, or AIDS. Gallo creates a blood test that can identify antibodies specific to HIV. This blood test to is essential to keeping the supply in blood banks pure.

DATE	INVENTION/MILESTONE
1984	**DNA profiling** (Alec Jeffreys): Noticing similarities and differences in DNA samples from his lab technician's family, Jeffreys discovers the principles that lead to DNA profiling, which has become an essential tool in forensics and the prosecution of criminal cases.
1984	**Imaging X-ray spectrometer** (George Edward Alcorn): Alcorn patents his device, which makes images of the source using X rays of specific energies, similar to making images with a specific wavelength (color) of light. It is used in acquiring data on the composition of distant planets and stars.
1985	**Industry Standard Architecture (ISA) bus** (Mark Dean and Dennis Moeller): Dean and Moeller design the standard way of organizing the central part of a computer and its peripherals, the ISA bus, which is patented in this year.
1985	**Windows operating system** (Bill Gates): The first version of Windows is released.
1986	**High-temperature superconductor** (J. Georg Bednorz and Karl Alexander Müller): Bednorz and Müller show that a ceramic compound of lanthanum, barium, copper, and oxygen becomes superconducting at 35 kelvins, a new high-temperature record.
1988	**Laserphaco probe** (Patricia Bath): Bath's probe is used to break up and remove cataracts.
1989	**World Wide Web** (Tim Berners-Lee and Robert Cailau): Lee finds a way to join the idea of hypertext and the young Internet, leading to the Web, coinvented with Cailau.
1989	**Method for tracking oil flow underground using a supercomputer** (Philip Emeagwali): Emeagwali receives the Gordon Bell Prize, considered the Nobel Prize for computing, for his method, which demonstrates the possibilities of computer networking.
1990	***BRCA1* gene discovered** (Mary-Claire King): King finds the cancer-associated gene on chromosome 17. She demonstrates that humans and chimpanzees are 99 percent genetically identical.
1991	**Carbon nanotubes** (Sumio Iijima): Although carbon nanotubes have been seen before, Iijima's 1991 paper establishes some basic properties and prompts other scientists' interest in studying them.
1991	**Nakao Snare** (Naomi L. Nakao): The Snare is a device that captures polyps that have been cut from the walls of the intestine, solving the problem of "lost polyp syndrome."
1993	**Flexible tailored elastic airfoil section** (Sheila Widnall): Widnall applies for a patent for this device, which addresses the problem of being able to measure fluctuations in pressure under unsteady conditions. She serves as secretary of the Air Force (the first woman to lead a branch of the military) and also serves on the board investigating the space shuttle *Columbia* accident of 1986.
1993	**Light-emitting diode (LED) blue and UV** (Shuji Nakamura): Nakamura's blue LED makes white LED light possible (a combination of red, blue, and green).
1993	**Mosaic** (Marc Andreessen): Andreessen launches Mosaic, followed by Netscape Navigator in 1995—the first Internet browsers. Both Mosaic and Netscape allow novices to browse the World Wide Web.
1995	**Global Positioning System** (Ivan A. Getting): The GPS system becomes fully operational.
1995	**51 Pegasi** (Michel Mayor and Didier Queloz): Mayor and Queloz detect a planet orbiting another normal star, the first extrasolar planet (exoplanet) to be found. As of June, 2009, 353 exoplanets were known.
1995	**iBot** (Dean Kamen): Kamen invents iBOT, a super wheelchair that climbs stairs and helps its passenger to stand.
1995	**Illusion transmitter** (Valerie L. Thomas): A concave mirror can produce a real image that appears to be three-dimensional. Thomas's system uses a concave mirror at the camera and another one at the television receiver.
1998	**UV Waterworks** (Ashok Gadgil): The device uses UV from a mercury lamp to kill waterborne pathogens.

Date	Invention/Milestone
1998	**PageRank** (Larry Page): The cofounder of Google with Sergey Brin, Page devises PageRank, the count of Web pages linked to a given page and a measure of how valuable people find that page.
1999	**BlackBerry** (Research in Motion of Canada): A wireless handheld device that began as a two-way pager, the BlackBerry is also a cell phone that supports Web browsing, e-mail, text messaging, and faxing—the first "smart" phone.
2001	**Segway PT** (Dean Kamen): Kamen introduces his personal transport device, a self-balancing, electric-powered pedestrian scooter.
2001	**iPod** (Tony Fadell): Fadell introduces the iPod, a portable hard-drive-based MP3 player with an Internet-based electronic music catalog, for Apple, Inc.
2003	**Aqwon** (Josef Zeitler): The hydrogen-powered scooter Aqwon can reach 30 miles (50 kilometers) per hour. Its combustion product is water.
2004	***SpaceShipOne* and *SpaceShipTwo*** (Burt Rutan): Rutan receives the U.S. Department of Transportation's first license issued for suborbital flight for *SpaceShipOne*, which shortly thereafter reaches an altitude of 328,491 feet. Rutan's rockets are the first privately funded manned rockets to reach space (higher than 100 kilometers above Earth's surface).
2005	**Nix and Hydra discovered** (Pluto companion team): The Hubble research team—composed of Hal Weaver, S. Alan Stern, Max Mutchler, Andrew Steffl, Marc Buie, William Merline, John Spencer, Eliot Young, and Leslie Young—finds these small moons of Pluto.
2005	**Eris** (Mike Brown and others): Working with C. A. Trujillo and D. L. Rabinowitz, Brown discovers Eris, the largest known dwarf planet and a Kuiper Belt object. It is 27 percent more massive than Pluto, another large Kuiper Belt object.
2007	**iPhone** (Apple, Inc.): Apple introduces its "smart phone," a combined cell phone, portable media player (equal to a video iPod), camera phone, Internet client (supporting e-mail and Web browsing), and text messaging device, to an enthusiastic market.
2008	**Retail DNA test** (Anne Wojcicki): Wojcicki (wife of Google founder Sergey Brin) offers an affordable DNA saliva test, 23andMe, to determine one's genetic markers for ninety traits. The product heralds what *Time* magazine dubs a "personal-genomics revolution."
2009	**Hubble Space Telescope repairs** (NASA): STS-125 astronauts conducted five spacewalks from the space shuttle *Atlantis* to upgrade the Hubble Space Telescope, extending its life to at least 2014.

Biographical Directory of Inventors

*The following list of more than 1,000 inventors briefly summarizes the achievements of not only the 413 inventors covered in this publication (starred with an asterisk *) but 598 others as well. Birth and death dates are followed by the individual's nationality and a brief description of his or her major achievements.*

A

Abalakov, Vitaly Mikhaylovich (1906-1986): Russian. The Abalakov Cam, developed in the 1930's, is for rock climbing. Three of four wheels have a projecting hump pivot on a common axle so that the device can be wedged into fissures and used for support.

ʿAbbas ibn Firnas* (810-887): Spanish Arab. In 875, ibn Firnas built a glider and flew it successfully but was injured upon landing.

Abel, John Jacob (1857-1938): American. An experimental pharmacologist, Abel is best known for his invention of the vividiffusion apparatus in 1912. A form of renal dialysis machine, it removed waste products from blood.

Abū al-Qāsim al-Zahrāwī (Abulcasis) (939-1013): Spanish Arab. Al-Zahrāwī wrote an encyclopedic medical text that was the standard resource for surgical techniques and invented many surgical instruments.

Acheson, Edward Goodrich* (May 9, 1856-July 6, 1931): American. A former assistant to Thomas Alva Edison, in 1891 Acheson synthesized carborundum, an industrial abrasive. Later, by heating it further, he produced pure graphite, a substance useful in lubricants and electrodes.

Adamian, Hovannes (1879-1932): Armenian Russian. In 1908 in Germany, Adamian registered a patent for a color television, the first person to do so. In 1925, he demonstrated his device, "Eristavi," which successfully sent three-color patterns and figures from one laboratory to another.

Adams, Thomas (1818-1905): American. Adams used the tropical tree resin chicle to make a flavored chewing gum. In 1888, Adams's Tutti-Frutti gum became the first to be sold in vending machines.

Adler, Robert (December 4, 1913-February 15, 2007): Austrian American. Among Adler's 150 patents is one for a wireless remote control for television sets, the Space Command, which used high-frequency sound waves.

Affel, Herman A. (August 4, 1893-October 13, 1972): American. In 1929, Affel patented his conduction system, comprising two concentric cylinders of conducting material separated by air: the coaxial cable, which made possible high-volume transcontinental telephone and television transmission.

Aiken, Howard (March 9, 1900-March 14, 1973): American. With Grace Hopper, Aiken designed the first of the electromechanical Mark series of computers, built in 1944. The U.S. Navy used it to calculate trajectories for projectiles.

Airy, George Biddell* (July 27, 1801-January 2, 1892): British. Airy's inventions included the optical method for correcting astigmatism in eyes and a method for compensating a compass on a metal ship.

Alçelik, Turhan (b. 1958): Turkish. An ophthalmologist, Alçelik developed a vehicle headlight system, road tested in 2004, capable of illuminating roads sufficiently for night driving without producing harmful glare.

Alcorn, George Edward* (b. March 22, 1940): American. Alcorn invented remote sensing instruments for spacecraft. In 1984, he received the NASA/Goddard Space Flight Center Inventor of the Year Award for his imaging X-ray spectrometer.

Alexanderson, Ernst* (January 25, 1878-May 14, 1975): Swedish American. Alexanderson, a pioneering telecommunications engineer, received more than 345 patents. His fame rests on his 1906 invention of the high-frequency alternator for long-wave transmissions.

Alexeyev, Rostislav Evgenievich (December 18, 1916-February 9, 1980): Russian. Alexeyev headed secret research in Russia to build high-speed ships. His vessels had stubby wings that enabled them to ride on a cushion of air over the sea surface. The prototype was built in 1966.

Alford, Andrew (August 5, 1904-January 25, 1992): Russian American. Alford devised the localizer antenna system, a ground-based system of radio signals that guides aircraft as they approach airport runways.

Allen, Samuel Leeds (May 5, 1841-November 26, 1918): American. During his career, Allen received patents for more than three hundred inventions, among them the Flexible Flyer, introduced in 1918. It was the first sled to be steered by hand.

Altschul, Randice-Lisa (b. 1961): American. Altschul originally worked designing toys and games, but in 1999, with the help of engineer Lee Volte, she patented the first disposable cell phone, the Phone-Card-Phone.

Álvarez, Luis W.* (June 13, 1911-September 1, 1988): American. Álvarez developed the liquid-hydrogen bubble chamber, which permitted fellow physicists to identify previously unknown fundamental particles. He received the 1968 Nobel Prize in Physics for it.

Ames, Nathan (November 17, 1826-August 17, 1865): American. In 1859, Ames registered patents for Revolving Stairs, the first escalator. It comprised steps mounted on a continuous belt in a triangular loop. While feasible, the device was never constructed.

Ancker-Johnson, Betsy (b. April 29, 1927): American. In 1966, Ancker-Johnson invented a generator that emits signals in the gigacycle range when a low-density plasma is created in a semiconductor resting in a high-intensity electrical field and low-intensity parallel magnetic field.

Anderson, Mary (1866-June 27, 1953): American. Anderson invented a device to clean windshields from inside the vehicle by a hand crank, the first windshield wiper (patented in 1903).

Andreessen, Marc* (b. July 9, 1971): American. Andreessen, along with Eric Bina, created Mosaic (released in 1993), the first Internet browser to present graphics and text together. He also developed Netscape Navigator.

Anschütz-Kaempfe, Hermann (October 3, 1872-May 6, 1931): German. In 1904, Anschütz-Kaempfe patented his gyrocompass and made later modifications that compensated for the distortions caused by a ship's motion at sea. The invention grew from his obsession to reach the North Pole.

Appert, Nicolas François (October 23, 1749-June 3, 1841): French. Appert was a grocer who in 1809 won a 12,000-franc prize from Napoleon Bonaparte for inventing a safe way to store food in jars, used to feed Napoleon's troops as he waged war throughout the world.

Archimedes* (c. 287-212 B.C.E.): Greek. Legendary for his mathematics, Archimedes also devised a catapult to defend his home city, a system of mirrors for focusing burning light on enemy ships, pulleys and levers for hoisting large ships, and, most famously, Archimedes' screw, a pump for raising water from wells.

Argand, François-Pierre-Ami (July 5, 1750-October 13, 1803): Swiss. In 1784, Argand patented his improved oil lamp. His experiments revealed that an adjustable cylindrical wick in a cylindrical chimney produced light many times brighter and cleaner than existing light sources.

Aristotle* (384-322 B.C.E.): Greek. Among Aristotle's many foundational contributions to philosophy and literary criticism was categorical logic.

Arkwright, Sir Richard* (December 23, 1732-August 3, 1792): English. Working with John Kay, in 1768 Arkwright produced the water frame, or spinning frame. Powered by a water wheel, it had two rollers that pulled cotton fibers taut and twisted them into fine yarn whose thickness could be adjusted.

Armstrong, Edwin H.* (December 18, 1890-January 31, 1954): American. Armstrong's regenerative circuit enabled the same vacuum tube to amplify a signal many times. In 1933, he invented a means to convey signals by modulating radio wave frequencies—FM radio.

Arnot, Arthur James* (August 26, 1865-October 15, 1946): Australian. Arnot is credited with inventing the electric drill, which others modified for industrial or home use.

Arnott, Neil (May 15, 1788-March 2, 1874): Scottish. A physician, Arnott invented the Arnott waterbed in 1832, which he later modified into a water-filled chair intended to counteract a ship's motion and prevent seasickness.

Artsimovich, Lev Andreevich (February 25, 1909-March 1, 1973): Russian. A leading Soviet physicist, Artsimovich led the team of scientists that built the first tokamak in the 1950's, a device that creates a doughnut-shaped electromagnetic field in order to sustain a controlled fusion reaction.

Ashraf, al- (c. 1242-November 22, 1296): Yemeni. About 1282, Sultan al-Ashraf, Umar ibn Yusuf, wrote an astronomical treatise in which he described an early mariner's compass: a bowl of water in which a magnetized compass floats.

Aspdin, Joseph (1778-March 20, 1855): English. Aspdin coined "Portland cement" for his invention, because the end product resembled Portland stone, an English limestone frequently used for construction.

Aston, Francis William (September 1, 1877-November 20, 1945): English. In 1919, Aston discovered how to separate two isotopes of neon—in a focused electromagnetic field, which moved the small-mass isotope, achieving separation. Thus was born the mass spectrograph, which helped earn him the 1922 Nobel Prize in Chemistry.

Atanasoff, John Vincent* (October 4, 1903-June 15, 1995): American. A mathematics professor, Atanasoff conceived the idea for a digital computer with electronics as the medium, base-two numbers, condensers for memory, and direct logical action for computation. He built the first prototype in 1939.

Ayrton, Hertha Marks* (April 28, 1854-August 26, 1923): English. Ayrton made improvements to the electric arc, an important nineteenth century illumination source, and invented a drafting tool and a manually operated fan.

B

Babbage, Charles* (December 26, 1791-October 18, 1871): English. Babbage's difference engine (described in 1822) and analytical engine (1834) were programmable mechanical computers. The first was designed to produce mathematical tables; the second was for all arithmetic calculations.

Babcock, Alpheus (September 11, 1785-April 3, 1842): American. Babcock was a musical instrument maker best known for patenting in 1825 a single-piece iron piano frame. His design enhanced resistance to strain, volume, and tonal range.

Babcock, George Herman (June 17, 1832-December 16, 1893): American. With Stephen Wilcox, Babcock devised a safe high-pressure water-tube boiler to produce steam for electricity generation, patented in 1867.

Backus, John Warner (December 3, 1924-March 17, 2007): American. In the 1950's, Backus developed the computer programming language Fortran. An acronym for "formula translation," it allows direct entry of commands into computers with Englishlike words and algebraic symbols.

Bacon, Francis (December 21, 1904-May 24, 1992): English. Although fuel cells date from the mid-nineteenth century, Bacon developed the first practical hydrogen-oxygen cell. The Bacon Cell, introduced in 1959, could generate five kilowatts.

Bacon, Roger* (c. 1220-c. 1292): English. Franciscan friar Bacon, among the first people to rely on experimentation to study nature, improved the understanding of optics, astronomy, and chemistry, including the manufacture of gunpowder.

Baekeland, Leo Hendrik* (November 14, 1863-February 23, 1944): Belgian American. Baekeland's Bakelite, a hard, moldable plastic introduced in 1909, was the first plastic made from synthetic materials and inaugurated the modern plastics age.

Baer, Ralph (b. March 8, 1922): German American. Baer developed the "Brown Box" in the 1960's, the first console video game. Magnavox began marketing it as Magnavox Odyssey in 1972.

Bagley, Rodney D. (b. October 2, 1934): American. With Irwin Lachlan and Ronald L. Lewis, Bagley invented the honeycomb cellular ceramic substrate that made possible an efficient catalytic converter to reduce pollutants from car exhaust.

Bain, Alexander* (October 10, 1810-January 2, 1877): Scottish. Introduced in 1846, Bain's "chemical telegraph" used punch tape to send signals that could be decoded on a moving paper tape soaked in ammonium nitrate and potassium ferrocyanide. His invention was five times faster than Morse code telegraphy.

Baird, John Logie (August 13, 1888-June 14, 1946): Scottish. The best known of Baird's 178 patents were a mechanical scanning system for transmitting moving images and a cathode-ray color television.

Baitar, Ibn al- (c. 1188-1248): Spanish. One of the greatest botanists of the Middle Ages, Ibn al-Baitar is credited with creating the first herbal drug treatment for cancer, using hindiba (chicory).

Bakr of Isfahan, Abi (fl. thirteenth century): Persian. In 1235, Bakr invented an astrolabe (an instrument for finding stars) that had a mechanical calendar to calculate the date. The astrolabe survives and is the oldest complete mechanical geared machine in existence.

Baldwin, Matthias (November 10, 1795-September 7, 1866): American. In 1830, Baldwin, a New Jersey manufacturer, built *Old Ironsides*, a six-ton locomotive of improved design. It was the first of some fifteen hundred locomotives his company built during his lifetime.

Ball, Harvey (July 10, 1921-April 12, 2000): American. Ball invented the yellow smiley face symbol in 1963 to cheer up workers at the State Mutual Life Assurance Company. Never having trademarked it, he received only $45 for the now ubiquitous image.

Bánki, Donát (June 6, 1859-August 1, 1922): Hungarian. With János Csonka, in 1898 Bánki invented a high-compression gasoline engine with two carburetors, an important step for the nascent automobile industry.

Banks, Robert (November 24, 1921-January 3, 1989): American. In 1951, Banks and Paul Hogan found a way to produce crystalline polypropylene and high-density polyethylene (HDPE), marking the beginning of a multibillion-dollar industry producing such common items as milk jugs, baskets, and indoor-outdoor carpeting.

Banneker, Benjamin* (November 9, 1731-October 9, 1806): American. In 1791, Banneker, a self-taught African American mathematician and astronomer, published his first almanac, providing information about eclipses, star and lunar positions, and weather based on his calculations.

Banting, Frederick Grant (November 14, 1891-February 21, 1941): Canadian. In 1922, Banting and Charles Herbert Best developed a method to produce insulin for treating diabetes. For this work, he received the 1923 Nobel Prize in Physiology or Medicine.

Baran, Paul (b. April 29, 1926): American. With Donald Davies and Leonard Kleinrock, Baran introduced the concept of digital packet switching to speed up the operation of digital networks and give them greater flexibility and hardiness.

Barber, John (1734-1801): English. Barber patented a design for a gas turbine in 1791. It was the first design to use a compressor and combustion chamber to ignite gases in order to turn the paddles of the turbine.

Bardeen, John* (May 23, 1908-January 30, 1991): American. Bardeen is the only person to win two Nobel Prizes in Physics, one for his part in inventing the transistor (1956) and the other for his explanation of superconductivity (1972).

Barnard, Christiaan Neethling (November 8, 1922-September 2, 2001): South African. Barnard headed the surgical team that performed the first heart transplant. It took place on December 3, 1967, in Cape Town, South Africa. The patient lived for eighteen days.

Barringer, Anthony Rene (b. October 20, 1925): English Canadian. In the early 1960's, Barringer invented the Induced Pulse Transient (INPUT) airborne electromagnetic system, used to hunt for ore. With it, mining engineers discovered twenty-five major deposits.

Barton, Otis (June 5, 1899-April 15, 1992): American. Barton designed the bathysphere, which he and William Beebe used in 1930 to become the first humans to dive below one hundred meters in the ocean.

Bascom, Earl W. (June 19, 1906-August 28, 1995): American. Bascom was a cowboy artist who invented equipment for rodeos, such as the side-delivery bucking chute (1916) and the hornless bronco saddle (1922).

Basov, Nikolay Gennadiyevich (December 14, 1922-July 1, 2001): Russian. Basov shared the 1964 Nobel Prize in Physics for his role in devising the quantum electronics that led to the maser and laser.

Bassal, Ibn (c. 1038-c. 1075): Spanish. Bassal is credited with being the first to add a flywheel to the rotating shaft of a pump in order to moderate fluctuations and smooth out the flow of power.

Bateman, C. Donald (b. March 8, 1932): Canadian. Bateman devised the ground proximity warning system to detect airplane navigational errors. The number of crashes plummeted after the system became mandatory in 1974.

Bath, Patricia* (b. November 4, 1942): American. An ophthalmologist, Bath developed a procedure and equipment for removing cataracts by laser surgery.

Battānī, al- (858-929): Turkish Arabic. Among the most illustrious of early astronomers, al-Battānī introduced trigonometry to astronomical calculation, laying the groundwork for spherical trigonometry.

Baulieu, Étienne-Émile (b. December 12, 1926): French. Baulieu developed RU 486 (mifepristone), an oral medication that causes the human womb to reject a fertilized egg. It is sometimes called the "abortion pill."

Baumann, Eugen (December 12, 1846-November 3, 1896): German. Baumann, a chemist, formulated polyvinyl chloride (PVC) in 1872. It is a hardy, nonreactive plastic widely used in pipes, clothing, and electrical wiring.

Baylis, Trevor Graham (b. May 13, 1937): English. Inspired by a television program about acquired immunodeficiency syndrome (AIDS) in Africa, in 1991 Baylis invented the wind-up radio as an inexpensive means to convey information about the disease in rural areas.

Beard, Andrew Jackson* (March 29, 1849-May 10, 1921): American. Beard received a patent for the Jenny coupler 1897. It enabled railroad cars to latch automatically by bumping into each other.

Beaufort, Francis (May 7, 1774-December 17, 1857): Irish. An admiral in the Royal Navy, Beaufort invented the Beaufort scale, a widely used tool for estimating wind strength without instruments.

Beckman, Arnold O. (April 10, 1900-May 18, 2004): American. Wealthy from his invention of a reliable pH meter (to measure acidity) in 1934, Beckman became a major donor for science education and research.

Bednorz, J. Georg* (b. May 16, 1950): German. Bednorz, with Karl Alexander Müller, discovered high-temperature superconductivity in a new class of ceramic materials, starting a worldwide effort to develop superconductor technology.

Beg, Ulugh (March 22, 1394-October 27, 1449): Persian. Beg built the largest astronomical observatory of its day and stocked it with instruments of his own design, notably a large Fakhri sextant that enabled him to take highly accurate measurements.

Begun, Semi Joseph* (December 2, 1905-January 5, 1995): German American. Begun built the first tape recorder used for broadcasting in 1934 and later improved the quality of magnetic tape for sound recording.

Békésy, Georg von* (June 3, 1899-June 13, 1972): Hungarian American. Békésy's discovery of the mechanics and physiology of hearing brought him the 1961 Nobel Prize in Physiology or Medicine.

Bélidor, Bernard Forest de (1698-September 8, 1761): French. De Bélidor's four-volume *Architecture hydraulique* (1737-1753) was the first major work to apply integral calculus to practical engineering problems.

Bell, Alexander Graham* (March 3, 1847-August 2, 1922): Scottish American. Before inventing the telephone in 1876, Bell taught at a school for the deaf, where he became fascinated by the nature of sound. He later produced innovations in aviation and hydrofoils and was the first president of the National Geographic Society.

Bell, Chichester A. (1848-1924): American. With his cousin Alexander Graham Bell, Chichester A. Bell started Volta Laboratory Association in 1881, where he helped develop an improved phonograph.

Benedictus, Edouard (1878-1939): French. Benedictus developed safety glass after knocking over a flask in 1903 and discovering that it did not break because of a nitrocellulose film on it.

Benerito, Ruth (b. January 12, 1916): American. Benerito's invention of wrinkle-resistant cotton cloth in the 1950's reduced the drudgery of ironing. The wash-and-wear fabric is credited with revitalizing the cotton industry.

Bennett, Willard H. (June 13, 1903-September 28, 1987): American. Bennett developed the radio frequency mass spectrometer in 1950. The nonmagnetic instrument was light enough to be carried in satellites later in the decade.

Benz, Carl* (November 25, 1844-April 4, 1929): German. Benz built the first commercial automobile powered by an internal combustion engine, the three-wheel Motorwagen, patented in January, 1886.

Berger, Hans (May 21, 1873-June 1, 1941): German. Berger devised the electroencephalograph in 1924 to record electrical patterns in the brain. It provides direct evidence about how human brains function.

Bergius, Friedrich* (October 11, 1884-March 30, 1949): German Argentine. Bergius devised a method for converting coal to liquid fuel by high-pressure hydrogenation, a development key to the German war effort in World War II.

Berliner, Emile* (May 20, 1851-August 3, 1929): German American. A versatile inventor, Berliner developed the microphone (1877), gramophone player (1887), and flat recording disc (1888). In 1919, he produced an early version of the helicopter.

Berners-Lee, Tim* (b. June 8, 1955): English. In 1989 Berners-Lee propounded his conception of a global hypertext project and wrote the first server and client for what became known as the World Wide Web.

Berry, Clifford* (April 19, 1918-October 30, 1963): American. Berry's contributions to the Atanasoff-Berry Computer (ABC, 1942) were its design details and construction; thereby, he proved that an electronic digital computer would work.

Berry, Marcellus F. (1848-1915): American. An employee of American Express Company, in 1891 Berry copyrighted his idea for traveler's checks to make it easier for travelers to obtain money in foreign countries.

Berthelot, Marcellin (October 27, 1827-March 18, 1907): French. The first chemist to synthesize hydrocarbons, in 1866 Berthelot was also the first to prepare polystyrene from ethylene and benzene.

Bessemer, Sir Henry* (January 19, 1813-March 15, 1898): English. In 1855, Bessemer patented a process for mass-producing steel economically. The Bessemer process introduces oxygen into fluid iron to remove impurities.

Best, Charles Herbert (February 27, 1899-March 31, 1978): Canadian. With Frederick Grant Banting, Best isolated the pancreatic hormone insulin in 1921, a key discovery for the treatment of diabetes.

Bevis, Douglas Charles Aitchison (May 28, 1919-June 25, 1994): English. In 1952, Bevis published the results of his research using amniocentesis to assess the risk factors to a fetus during pregnancy, a landmark in prenatal health.

Bi Sheng (c. 990-c. 1051): Chinese. Bi Sheng, an engraver, invented movable, reusable type, producing three thousand wood blocks with individual Chinese characters. He later made the type fonts from porcelain.

Bigelow, Erastus Brigham (April 2, 1814-December 6, 1879): American. Bigelow devised power looms for weaving counterpanes, coach lace, carpets, silk brocatelle, and tapestry and founded Clinton, Massachusetts, to support his industrial works.

Binney, Edwin* (1866-December 18, 1934): American. In 1903, Binney and his partner C. Harold Smith marketed the first wax toy crayons in a box of eight colors.

Binnig, Gerd* (b. July 20, 1947): German. With Heinrich Rohrer, Binning developed the scanning tunneling microscope, capable of imaging a single atom. They shared the 1986 Nobel Prize in Physics for it.

Bird, Forrest M. (b. June 9, 1921): American. Besides devising respirators for crews in high-altitude aircraft, in 1958 Bird invented the Bird Universal Medical Respirator for cardiopulmonary care and later a pediatric respirator.

Birdseye, Clarence* (December 9, 1886-October 7, 1956): American. Birdseye perfected a quick-freeze method for frozen foods that preserved without causing extensive cellular damage. Wrapped in his coated cellophane, his products were first sold in 1930.

Bíró, László (September 19, 1899-November 24, 1985): Hungarian Argentine. Irritated by the difficulties of using a fountain pen and taking a cue from the rotary inker on printing presses, Bíró, a journalist, invented the ballpoint pen in 1943.

Bīrūnī, al- (September, 973-December 13, 1048): Persian. A scholar of vast learning, al-Bīrūnī championed the experimental method to increase knowledge. He invented several astronomical instruments, including a mechanical computer for calculating the date based on Moon phases and the solar year.

Bissell, Melville (September 24, 1843-March 15, 1889): American. Bissell built the first carpet sweeper machine (patented 1876) to make it easier for his wife, Anna, to clean up the clingy sawdust on the floor of their crockery shop.

Black, Harold Stephen (April 14, 1898-December 11, 1983): American. Black's 1927 invention of the negative feedback amplifier, which feeds a system's output back into the input, proved broadly important to electronics, increasing bandwidth and reducing distortion in telephone, radio, and telegraphy systems.

Blackton, J. Stuart (January 5, 1875-August 13, 1941): English American. Inspired by the motion pictures of Thomas Alva Edison, Blackton produced the first stop-frame animation, premiering *Humorous Phases of a Funny Face* in 1906.

Blanchard, Helen Augusta (1840-1922): American. In 1873, Blanchard patented a sewing machine capable of zigzag stitching and held twenty-eight patents in all, including ones for a pencil sharpener and elastic seams and gores.

Blanchard, Thomas (June 24, 1788-April 16, 1864): American. Blanchard advanced industrial production with several major inventions, especially the acentric lathe, which reproduces irregular forms from a pattern (patented 1819).

Bláthy, Ottó Titusz (August 11, 1860-September 26, 1939): Hungarian. Bláthy's close-core electrical transformer, developed in 1885 with Károly Zipernowsky and Miksa Déri, made it possible to transmit alternating current over long distances.

Blodgett, Katharine Burr* (January 10, 1898-October 12, 1979): American. The first woman to become a research scientist for General Electric, Blodgett invented nonreflecting glass in 1938 by coating regular glass with many layers of a fatty acid film, each one molecule thick.

Blum, Samuel (b. August 28, 1920): American. Blum first used the ultraviolet excimer laser for medical applications, notably laser-assisted in situ keratomileusis (LASIK) eye surgery to correct vision defects.

Blumberg, Baruch S. (b. July 28, 1925): American. In 1976, Blumberg was cowinner of the Nobel Prize in Physiology or Medicine with D. Carleton Gajdusek for developing a diagnostic test for hepatitis B and a vaccine.

Bobeck, Andrew H. (b. 1926): American. Bobeck and Robert F. Fischer invented bubble memory for data storage systems.

Bogardus, James (March 14, 1800-April 13, 1874): American. Bogardus pioneered the use of cast-iron frames as the load-bearing structure for buildings and erected the first entirely cast-iron building in 1847.

Bohlin, Nils Ivar (July 17, 1920-September 21, 2002): Swedish. An engineer for Volvo Car Corporation, Bohlin designed the three-point seat belt (side-fastened lap belt with a diagonal chest strap), introduced in 1959.

Boivin, Marie Anne Victoire* (April 9, 1773-May 16, 1841): French. A leading expert in midwifery, Boivin invented the Boivin bivalve vaginal speculum.

Bombardier, Joseph-Armand (April 16, 1907-February 18, 1964): Canadian. Bombardier built his first snowmobile in 1937, a boxy seven-passenger vehicle, but it was his agile, motorcyclelike Ski-Doo, marketed in 1959, that transformed winter sports.

Booth, Andrew Donald (b. February 11, 1918): English Canadian. In 1948, Booth devised the magnetic drum used in early computers, the equivalent of the modern hard drive.

Booth, H. Cecil* (July 4, 1871-January 18, 1955): English. Booth patented his vacuum cleaner in 1901. The "Puffing Billy," it is claimed, cleaned the carpets for the coronation of Edward VI a year later.

Borden, Gail, Jr. (November 9, 1801-January 11, 1874): American. Borden developed a process for condensing milk in 1856. During the Civil War, the Union army's demand for the spoilage-resistant milk made it a commercial success.

Bosch, Carl* (August 27, 1874-April 26, 1940): German. Bosch adapted the high-pressure synthesis of ammonia for large-scale commercial production, a key step in the creation of cheap nitrogen fertilizers. For this he shared the 1931 Nobel Prize in Chemistry.

Bose, Amar (b. November 2, 1929): American. Chairman of Bose Corporation, Bose innovated high-fidelity sound with the introduction of the 901 Direct/Reflecting speaker in 1968, the first capable of producing rich, panoramic sound.

Bose, Jagadish Chandra (November 30, 1858-November 23, 1937): Indian. Bose's wide-ranging intellect was directed toward plant physiology, science fiction, and mysticism, among other matters, but he is best known for broadcasting wireless microwave signals in 1895, a first.

Bothe, Walther* (January 8, 1891-February 8, 1957): German. Bothe designed the device and developed the procedures that made possible the coincidence method of particle detection, crucial to the development of nuclear physics.

Bower, Robert W. (b. June 12, 1936): American. In 1969, Bower patented his Self-Aligned Gate MOSFET (metal-oxide semiconductor field-effect transmitter), a basic component of integrated circuits.

Boyden, Seth (November 17, 1788-March 31, 1870): American. A versatile industrial inventor, Boyden produced innovations in patent leather, malleable iron castings, steam engines, hat and nail manufacturing, and strawberries.

Boyer, Herbert Wayne* (b. July 10, 1936): American. With Stanley Norman Cohen in 1973, Boyer created the first viable deoxyribonucleic acid (DNA) cloned from different types of bacteria—recombinant DNA, now a basic technique in genetic engineering.

Boykin, Otis* (August 29, 1920-March, 1982): American. Boykin's designs for electronic resistors and other devices enabled faster, cheaper manufacturing of basic electrical and electronic components.

Boyle, Willard S.* (b. August 19, 1924): Canadian. With George E. Smith, Boyle invented the charge-coupled device (CCD) in 1969, which enhances digital images. Boyle also built the first continuously pumped ruby laser.

Bradley, Milton (November 8, 1836-May 30, 1911): American. In 1864, Bradley launched Milton Bradley and Company to market his innovation, the printed board game.

Bragg, William Henry (July 2, 1862-March 10, 1942): English. With his son William Lawrence, Bragg shared the 1915 Nobel Prize in Physics for founding a new branch of science, the analysis of crystal structure by X-ray diffraction.

Bragg, William Lawrence (March 31, 1890-1971): English. Bragg became the youngest Nobel laureate when, at age twenty-five, he shared the physics prize with his father, William Henry, for inventing X-ray crystallography.

Braille, Louis* (January 4, 1809-January 6, 1852): French. Between the ages of twelve and fifteen, Braille developed the raised-dot writing system for the blind that still bears his name.

Branca, Giovanni* (April 22, 1571 [baptized]-January 24, 1645): Italian. In 1629, Branca published *Le machine*, containing innovative designs, including one for the first steam turbine.

Brandenberger, Jacques Edwin* (October 19, 1872-July 13, 1954): Swiss. In 1908, Brandenberger, a chemist, produced a thin sheet of cellulose that repelled liquids, greases, and bacteria, which made it ideal for packaging food. He named it cellophane.

Brannock, Charles F. (May 16, 1903-November 22, 1992): American. The Brannock device, invented in 1925 and still standard in the shoe industry, measures the dimensions of feet accurately enough to ensure proper fitting.

Brattain, Walter H.* (February 10, 1902-October 13, 1987): American. Brattain shared the 1956 Nobel Prize in Physics with John Bardeen and William Shockley for their invention of the transistor. His part was to test Shockley's arrangements of semiconductors.

Braun, Karl Ferdinand* (June 6, 1850-April 20, 1918): German. For his 1897 invention of the oscilloscope, a precursor to the television, and other electronics devices, Braun shared the 1909 Nobel Prize in Physics with Guglielmo Marconi.

Braun, Wernher von* (March 23, 1912-June 16, 1977): German American. Von Braun was a designer and motivating spirit for German rockets during World War II and the American space effort afterward.

Brearley, Harry (February 18, 1871-August 12, 1948): English. By adding chromium to steel, Brearley synthesized stainless steel in 1913, initially to keep rifle barrels from rusting.

Breed, Allen K. (July 27, 1927-December 13, 1999): American. Breed built the first electromechanical automotive air bag safety system in 1968 and founded Breed Corporation, which became the third-largest supplier of automotive safety devices in the world.

Brin, Sergey (b. August 21, 1973): Russian American. In 1998, with Larry Page, Brin unveiled Google, an Internet search engine based on his data mining system. Google, Inc., swiftly grew into the world's largest Internet company.

Brown, Rachel Fuller (November 23, 1898-January 14, 1980): American. Working with Elizabeth Lee Hazen, Brown synthesized nystatin, the first antifungal antibiotic, introduced as a medication for humans in 1954.

Browning, John Moses* (January 21, 1855-November 26, 1926): American. Browning designed many types of sports rifles, shotguns, and pistols but is best known for the Peacemaker (1890) and the Browning automatic rifle (BAR, 1917).

Brugnatelli, Luigi Gasparo (1761-1818): Italian. Brugnatelli developed electroplating in 1805, which he used to deposit a fine layer of gold over silver objects.

Brush, Charles Francis (March 17, 1849-June 15, 1929): American. Brush invented a direct-current generator, an electrical arc light, a method for manufacturing lead-acid batteries, and, in 1888, the first wind-powered electrical turbine.

Budding, Edwin Beard (1795-1846): English. Budding built the first mechanical lawn mower in 1830, conceiving of the invention while watching the bladed reel of a cutting machine in a cloth mill.

Bullock, William* (1813-April 12, 1867): American. Bullock revolutionized the newspaper business with his invention of the roll-fed rotary printing press, patented in 1863.

Bunsen, Robert Wilhelm* (March 31, 1811-August 16, 1899): German. Bunsen's burner, first described in 1860 and built by Peter Desaga, provides a high-temperature, nonluminous flame and quickly became a standard piece of laboratory equipment.

Burbank, Luther* (March 7, 1849-April 11, 1926): American. Through various hybridization techniques, Burbank created hundreds of varieties of fruits, vegetables, and flowers, most famously the Russet Burbank (Idaho) potato.

Burckhalter, Joseph H. (October 9, 1912-May 9, 2004): American. With Robert Seiwald, Burckhalter synthesized fluorescein isothiocyanate (FITC), an antibody labeling agent that proved valuable in identifying the causes of disease.

Burroughs, William Seward* (January 28, 1855-September 15, 1898): American. In 1888, Burroughs patented the first adding machine that was easy enough to use and reliable enough to be a commercial success.

Burton, William Meriam (November 17, 1865-December 29, 1954): American. In 1913, Burton worked out a method for cracking crude oil with high pressure and high temperature, which doubled gasoline production for the fledgling petroleum industry.

Bush, Vannevar (March 11, 1890-June 30, 1974): American. Bush pioneered the design and construction of electromechanical analog computers and was the first to describe the idea of hypertext.

Bushnell, David* (August 30, 1742-1824): American. Bushnell designed and built the first attack submarine, the *Turtle*, used unsuccessfully against a British ship during the Revolutionary War.

Bushnell, Nolan K.* (b. February 5, 1943): American. In 1972, Bushnell released *Pong*, the first commercially successful video game, through his start-up company, Atari.

Butts, Alfred (April 13, 1899-April 4, 1993): American. Butts invented Scrabble, released in 1948 and still among the most popular board games in the world.

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Cai Lun* (c. 50-c. 121 C.E.): Chinese. About the year 105, Cai Lun invented the process for making paper by suspending felted fibers in water until they dried into thin sheets.

Cailliau, Robert* (b. January 26, 1947): Belgian. Cailliau helped Tim Berners-Lee develop the World Wide Web while they worked at the European Organization for Nuclear Research (CERN) in 1990.

Calahan, Edward (1838-1912): American. Calahan built the first stock ticker in 1863. Receiving data through the telegraph directly from the New York Stock Exchange, the machines could print out the values of stock, commodities, and bonds in offices nationwide.

Calmette, Albert (July 12, 1863-October 29, 1933): French. With Camille Guérin, Calmette synthesized a tuberculosis vaccine, and he later developed a diagnostic test for the disease, called Calmette's reaction.

Campbell, Donald L. (August 5, 1904-September 14, 2002): American. In 1942, Campbell contributed to the development of fluid catalytic cracking, a chemical process essential for high-yield refining of high-octane gasoline and heating oil from crude oil.

Campbell, John* (c. 1720-December 16, 1790): Scottish. Campbell helped develop the nautical sextant, an essential instrument for navigation.

Camras, Marvin* (January 1, 1916-June 23, 1995): American. Camras invented a recording device using magnetized piano wire to record the voice of his cousin, a singer. He later adapted the idea to magnetic tape and the multitrack tape recorder that transformed the recording industry.

Carlson, Chester F.* (February 8, 1906-September 19, 1968): American. Carlson first tested his process for electrophotography, or xerography, in 1938, making the first photocopy.

Carothers, Wallace Hume* (April 27, 1896-April 29, 1937): American. Working for Dupont, Carothers, a chemist, led a research team that synthesized nylon and neoprene, the first artificial polymer-based products that were comparable to natural materials.

Carpue, Joseph Constantine (May 4, 1764-January 30, 1846): English. An anatomist and surgeon, Carpue pioneered surgical techniques for rhinoplasty, re-creating a missing nose with skin and integuments from the patient's forehead.

Carrier, Willis* (November 26, 1876-October 9, 1950): American. Carrier provided relief from heat and humidity through his invention of the modern air conditioner in 1902.

Carruthers, George R.* (b. October 1, 1939): American. Carruthers invented ultraviolet imaging devices—a camera and a spectrograph—that detect pollutants in Earth's atmosphere. A camera of his design took photographs of the Moon during the Apollo 16 mission in 1972.

Carson, Benjamin S. (b. September 18, 1951): American. Carson led the Johns Hopkins University surgical team that in 1987 was the first to separate Siamese twins who were joined at the head, hailed as the most complex surgical feat in medical history.

Cartwright, Alexander J. (April 17, 1820-July 12, 1892): American. Cartwright established the first baseball club (the Knickerbocker Base Ball Club) in 1845 and published the first set of rules; accordingly, he is often cited as the game's inventor.

Cartwright, Edmund* (April 24, 1743-October 30, 1823): English. Cartwright's powered weaving machine, patented in 1785, revolutionized textile manufacture, a signal advance into the Industrial Revolution.

Carver, George Washington* (July 12, 1861?-January 5, 1943): American. Born a slave, Carver became a leading agricultural researcher, inventing a multitude of useful products from such plants as the peanut, sweet potato, and soybean while at the Tuskegee Institute in Alabama.

Caselli, Giovanni (1815-1891): Italian. In 1861, Caselli patented the pantelegraph, a precursor of the fax machine that transmitted images via telegraph lines.

Cayley, George* (December 27, 1773-December 15, 1857): English. In 1904, Cayley built the first successful model monoplane glider, which had a kite for lift attached to a pole with an adjustable cross-shaped tail for stability and control.

Cepollina, Frank J. (b. 1936): American. Having worked on the Hubble Space Telescope for the National Aeronautics and Space Administration (NASA) since the mid-1970's, Cepollina designed the servicing platforms and instrument carriers that led to the successful repair of the telescope in 1993.

Cerf, Vinton Gray* (b. June 23, 1943): American. Cerf codesigned the packet network interconnection protocols (TCP/IP) that became the groundwork for the Internet.

Chapin, Daryl (July 21, 1906-January 19, 1995): American. With Calvin Fuller and Gerald Pearson, in 1954 Chapin demonstrated their Bell Solar Battery, which directly converts sunlight into electricity.

Chappelle, Emmett W. (b. October 24, 1925): American. With Grace Picciolo, Chappelle developed a bioluminescent assay from the luciferase enzyme and luciferin found in fireflies. The assay, important to agriculture, detects the presence of adenosine triphosphate (ATP).

Chardonnet, Hilaire Bernigaud (May 1, 1839-March 11, 1924): French. In 1889, Chardonnet exhibited his artificial silk, made from cellulose nitrate, at the Paris Exhibition. This "Chardonnet silk" is a form of rayon.

Charnley, John (August 29, 1911-August 5, 1982): English. Charnley invented the low-friction artificial hip and developed the surgical techniques for emplacing it (total hip arthroplasty) to treat osteoarthritis of the hip joint.

Chernoff, Adrian (b. 1971): American. In addition to being a leading automobile engineer, Chernoff created Rubber Bandits, rubber bands with hardy attached labels used in bundling and organizing items.

Christensen, Niels (1865-1952): Danish American. Christensen devised the O-ring in 1933. It is widely used to form a hydraulic seal for a piston in a cylinder.

Christie, Samuel Hunter (May 22, 1784-January 24, 1865): English. In 1833, Christie described his method for comparing the resistances of wires of different thicknesses in a diamond-shaped circuit. The method later became known as the Wheatstone bridge.

Cierva, Juan de la (September 21, 1895-December 19, 1936): Spanish. De la Cierva built the first autogiro, a propeller-powered aircraft whose lift is provided by a rotor, like that of a helicopter. He tested it successfully in 1923.

Ciurcu, Alexandru (January 29, 1854-January 22, 1922): Romanian. With Just Buisson, in 1886 Ciurcu built a reaction engine that propelled a boat by combusting gases in a cylinder that had been introduced through a small hole.

Clarke, Arthur C. (December 16, 1917-March 18, 2008): English. In 1945, Clarke published a technical article in *Wireless World*, "Extra-terrestrial Relays," containing the first description of a system of communication satellites.

Claude, Georges* (September 24, 1870-May 23, 1960): French. In 1910, Claude succeeded in producing a bright red light by electrifying neon in a glass tube, the first neon lamp.

Coanda, Henri Marie (June 6, 1886-November 25, 1972): Romanian. In 1910, Coanda built his Turbine Aeroplane, a biplane propelled by an early jet engine that used a four-cylinder piston engine to compress air that was then ignited in two burner chambers.

Cochran, Josephine Garis* (March 8, 1839-August 3, 1913): American. Fed up with servants chipping her dinnerware, Cochran designed the first dishwashing machine, patented in 1886.

Cockerell, Sir Christopher* (June 4, 1910-June 1, 1999): English. Cockerell launched the first hovercraft in 1959. Capable of carrying four passengers, the seven-ton vessel rode over the water on a cushion of air at speeds up to 28 miles per hour.

Coffey, Aeneas (1780-1852): Irish. Although an excise agent who hunted illegal whiskey makers, in 1830 Coffey invented an improved column still capable of continuous production of high-grade alcohol.

Cohen, Adam (b. May 30, 1979): American. Cohen's anti-Brownian Electrokinetic trap (ABEL trap) isolates and manipulates individual fluorescent molecules in solution at room temperature. It is a tool for analyzing complex molecules.

Cohen, Stanley (b. November 17, 1922): American. Working with Rita Levi-Montalcini, Cohen isolated human growth factors, which led to improved understanding and treatment of many degenerative and developmental diseases.

Cohen, Stanley Norman* (b. February 17, 1935): American. Cohen, with Herbert Wayne Boyer, was the first scientist to synthesize a functional recombinant DNA molecule, a basic advance for genetic engineering.

Collip, James Bertram (November 20, 1892-June 19, 1965): Canadian. Part of Frederick Grant Banting's research team, Collip, a biochemist, produced the first purified insulin suitable for use in human beings.

Colt, Samuel* (July 19, 1814-January 10, 1862): American. In 1835, Colt obtained the first patent on a revolver, whose rotating cylinder automatically fed cartridges into the firing chamber.

Colton, Frank B. (March 3, 1923-November 25, 2003): Polish American. A research chemist, Colton invented Enovid. First used to treat menstrual disorders, it was introduced in 1960 as an oral contraceptive.

Congreve, William (May 20, 1772-May 16, 1828): English. Congreve invented a solid-fuel artillery rocket capable of traveling nine thousand feet. The "rockets' red glare" in "The Star-Spangled Banner" refers to Congreve rockets during the War of 1812.

Conover, Lloyd Hillyard (b. June 13, 1923): American. Conover developed the antibiotic tetracycline in 1952. Within three years, it was the most-prescribed broad-spectrum antibiotic in the United States.

Constantinescu, George (1881-1965): Romanian. Constantinescu invented an interrupter gear that permitted machine guns to fire between the blades of propellers on the fighter planes of World War I.

Conti, Piero Ginori (June 3, 1865-December 9, 1939): Italian. Conti built the first geothermal power plant in 1904, which powered a 10-kilowatt dynamo.

Cooke, William Fothergill* (May 4, 1806-June 25, 1879): English. Working with Charles Wheatstone, Cooke pioneered electric telegraphy in Great Britain.

Coolidge, William David* (October 23, 1873-February 3, 1975): American. Coolidge invented a vacuum tube for generating X rays, which he patented in 1913. He also developed a portable X-ray machine for medical use during World War I.

Cooper, Martin* (b. December 26, 1928): American. Working for Motorola, Cooper led the research effort to develop the first wireless mobile telephone.

Cooper, Peter* (February 12, 1791-April 4, 1883): American. Cooper invented a series of industrial processes and first demonstrated the capabilities of the steam locomotive on American railways.

Coover, Harry (b. March 6, 1919): American. While trying to develop transparent gun sights for use in World War II, Coover found that one class of substance, cyanoacrylates, are unusually sticky. At Eastman Kodak, he refined the discovery into a useful product, superglue, first marketed in 1958.

Copeman, Lloyd Groff (December 29, 1881-July 5, 1956): American. Copeman produced the first electric stove in 1909 and later established the Copeman Electric Stove Company to market it, as well as his automatic electric toaster.

Corliss, George (June 2, 1817-February 21, 1888): American. The Corliss steam engine, developed in the late 1840's, was much more efficient than previous designs because of its novel rotary valves and variable valve timing.

Corneliszoon, Cornelis (1550-1607): Dutch. In 1594, Corneliszoon converted the turning motion from a windmill via a crankshaft to move a blade up and down and saw wood: the first powered sawmill.

Coston, Martha J.* (April 10, 1828-January 12, 1904): American. Building on her deceased husband's idea, Coston devised and in 1871 patented a system of signal flares with which ships could communicate at night.

Cottrell, Frederick Gardner* (January 10, 1877-November 16, 1948): American. Cottrell invented the electrostatic precipitator, patented in 1907, which ionizes pollutants, such as dust and smoke, so that they can be removed by electrified plates.

Coulter, Wallace (February 17, 1913-August 7, 1998): American. The Coulter principle is a reference method for counting and sizing microscopic particles in a fluid. It proved a great improvement in assaying blood.

Cousteau, Jacques* (June 11, 1910-June 25, 1997): French. Cousteau opened underwater realm to adventurers and spectators, creating the Aqua-Lung with Emile Gagnan in 1943 and pioneering underwater photography.

Cowen, Joshua Lionel* (August 25, 1877-September 8, 1965): American. Cowen's Lionel electric toy trains set the standard for the market.

Coxe, Eckley Brinton (June 4, 1839-May 13, 1895): American. A mining engineer and mine operator, Coxe improved the safety and efficiency of coal mining through several inventions, including a coal-washing jig, corrugated rolls for breaking coal, and a mechanical stoker.

Crary, John Williamson (1814-1897): American. In 1858, Crary invented a brickmaking machine that produced bricks of uniform size and quality.

Cray, Seymour* (September 28, 1925-October 5, 1996): American. By densely packing together hundreds of thousands of computer chips, in 1963 Cray built the first supercomputer, the CDC 6600. The supercomputer proved invaluable to scientific research, weather forecasting, and engineering.

Cristofori, Bartolomeo* (May 4, 1655-January 27, 1732): Italian. Cristofori is credited with building the first piano (then known as the pianoforte) about 1709. Its key innovation lay in producing sound by hammering strings rather than plucking them, as does the harpsichord.

Crompton, George (March 23, 1829-December 29, 1886): English American. Crompton simplified power looms and made them more efficient and flexible through a series of improvements, taking his first patent in 1854.

Crookes, Sir William* (June 17, 1832-April 4, 1919): English. A great experimenter, Crookes discovered thallium and invented the radiometer, the spinthariscope for detecting alpha particles, and the Crookes tube, a vacuum tube that produces cathode rays (electrons).

Crosby, Caresse* (April 20, 1892-January 24, 1970): American. Born Mary Phelps Jacob, Crosby received a patent for a wireless brassiere in 1914, the first design to be thus protected. She later became a celebrated poet and publisher.

Cruikshank, William Cumberland (1745-1800): English. Cruikshank introduced chlorination to make water safe to drink.

Crum, George (1822-1914): American. Crum is credited with inventing the potato chip in 1853, which he served but never patented.

Csonka, János (January 22, 1852-October 27, 1939): Hungarian. With Donát Bánki, Csonka invented the carburetor in 1893. They also produced the first motor tricycle and a gas engine.

Ctesibius of Alexandria* (c. 290-probably after 250 B.C.E.): Greek. Ctesibius, the "father of pneumatics," invented the force pump and water organ and refined the water clock.

Cugnot, Nicolas-Joseph* (February 26, 1725-October 2, 1804): French. In 1769, Cugnot built a steam-powered cart to haul artillery for the French army, and a year later he devised a vehicle that could carry four people.

Cullen, William (April 15, 1710-February 5, 1790): English. A medical chemist, Cullen is credited with creating the first workable design for a refrigerator (1748). His was a proof-of-concept device and never saw practical use.

Curtiss, Glenn H.* (May 21, 1878-July 23, 1930): American. A pioneering aviator, Curtiss introduced the aileron to provide airplanes with lateral stability. He also built the first successful seaplane.

Cushman, David Wayne (November 15, 1939-August 14, 2000): American. In the 1970's with Miguel Ondetti, Cushman developed captopril, the first angiotensin-converting enzyme (ACE) inhibitor, as an oral medication to control hypertension.

D

Daguerre, Louis Jacques* (November 18, 1787-July 10, 1851): French. In 1837, Daguerre, a painter and printmaker, perfected a process for chemically developing latent photographic images, which became known as daguerreotypes.

Daimler, Gottlieb* (March 17, 1834-March 6, 1900): German. With Wilhelm Maybach, Daimler built the first modern internal combustion engine with a gasoline-injecting carburetor in 1882, using various models to power a boat, bicycle, and carriage.

Dalén, Nils Gustaf* (November 30, 1869-December 9, 1937): Swedish. Dalén invented a fuel-saving, reliable acetylene gas lighting system for lighthouses and buoys, a boon to seafarers. He received the 1912 Nobel Prize in Physics for this invention.

Damadian, Raymond* (b. March 16, 1936): American. In 1974, Damadian patented the design for a nuclear magnetic resonance device to detect cancer and in 1977 produced the first magnetic resonance imaging (MRI) scan of the human body.

Darby, Abraham* (c. 1678-May 8, 1717): English. In 1709, Darby devised a coke-fueled blast furnace capable of producing high-grade iron, a significant step toward the Industrial Revolution.

Darby, Newman (b. 1928): American. Darby attached a movable sail to a pontoon catamaran in 1948, creating the first sailboard and inventing windsurfing.

D'Armate, Salvino (c. 1258-c. 1317): Italian. D'Armate is credited with inventing eyeglasses sometime in the late thirteenth century. He did so in hopes of achieving a direct view of God.

Darrow, Charles (1889-August 29, 1967): American. An engineer, in 1933 Darrow created Monopoly, which became the most popular board game ever.

Davies, Donald Watts (June 7, 1924-May 28, 2000): English. The Internet depends upon packet switching, a means of communication between computers that Davies conceived in 1965.

Davis, Jacob (1834-1908): Latvian American. Using Levi Strauss's denim cloth, Davis invented blue jeans with riveted pockets for extra strength, which he patented with Strauss in 1873.

Davy, Edmund (1785-November 5, 1857): English. In 1836, Davy created acetylene by heating potassium carbonate to high temperatures and letting it react with water.

Davy, Sir Humphry* (December 17, 1778-May 29, 1829): English. A renowned chemist, Davy also invented the miner's safety lamp, which made it possible for coal miners to work in methane-laden air.

Day, Joseph (1855-1946): English. In 1891, Day built the valveless two-stroke engine, a lightweight design that later was widely used in small vehicles and machines.

Dean, Mark* (b. March 2, 1957): American. With Dennis Moeller, Dean designed the Industry Standard Architecture (ISA) bus that enables users to hook up peripheral devices to their personal computers.

DeBakey, Michael Ellis (September 7, 1908-July 11, 2008): American. In 1966, DeBakey performed the first implantation of a left ventricle assist device (LVAD), a type of artificial heart.

Deere, John* (February 7, 1804-May 17, 1886): American. In 1837, Deere produced the first self-scouring steel plow, widely used by homesteaders in midwestern America.

De Forest, Lee* (August 26, 1873-June 30, 1961): American. In 1906, De Forest built the first three-element electron vacuum tube—the triode—which he called the audion. It could amplify signals and generate oscillations for transmitting sound via radio.

De Groote, Melvin (1896-February, 1963): American. An industrial chemist, De Groote synthesized demulsifiers for purifying crude oil of salt, sulfur, and water.

Dennard, Robert (b. September 5, 1932): American. In 1967, Dennard invented the one-transistor dynamic random access memory (DRAM), a crucial advance in computer technology.

Devol, George (b. February 20, 1912): American. A pioneer in robotics, Devol obtained more than forty patents, including one for Unimate (1954), the first industrial robot.

Dewar, Sir James* (September 20, 1842-March 27, 1923): English. Among Dewar's wide-ranging achievements as a chemist was his invention of the double-walled flask in 1872, later marketed to the public as the Thermos.

Dham, Vinod K. (b. 1950): Indian American. In 1990, Dham led the team at Intel Corporation to create the Pentium (586) processor chip, and in 1996 he oversaw the development of Advanced Micro Device's K6 processor.

Dickson, Earle (October 10, 1892-September 21, 1961): American. Because his wife was accident-prone, Dickson kept handy a supply of gauze pads on surgical tape. Johnson and Johnson learned of his invention and in 1924 began manufacturing it as the Band-Aid adhesive bandage.

Dickson, William Kennedy Laurie (August 3, 1860-September 28, 1935): English. In 1890, while an engineer in the laboratory of Thomas Alva Edison, Dickson built a motion-picture camera, the kinetograph, and made a short film called *Monkeyshines*.

Diehl, Philip (January 29, 1847-April 7, 1913): German American. Diehl attached a fan blade to a sewing machine motor and hung it on the ceiling. He patented his ceiling fan in 1887, later incorporating a light in the design.

Diesel, Rudolf* (March 18, 1858-September 29, 1913): German. The diesel engine, which Diesel successfully built in 1893, was an internal combustion engine that used pressure rather than a spark to ignite fuel.

Din, Taqi al- (June 14, 1526-1585): Turkish. One of al-Din's many books, *The Sublime Methods of Spiritual Machines* (1551), outlines the design of a rudimentary steam turbine, which he proposed be used for turning meat on a spit.

Disney, Walt* (December 5, 1901-December 15, 1966): American. Disney's studio produced the first cartoon with a synchronized sound track, *Steamboat Willie* (1928), and the first short feature to use the multiplane camera technique, *The Old Mill* (1937).

Djerassi, Carl* (b. October 29, 1923): Austrian American. With Luis Miramontes and George Rosenkranz, in 1951 Djerassi produced an oral contraceptive pill containing norethisterone synthesized from progesterone, which inhibits ovulation.

Dobelle, William H. (October 24, 1941-October 5, 2004): American. Dobelle invented an artificial vision system for the blind in which a minicamera mounted on sunglasses feeds images though sixty-eight electrodes to the visual cortex after processing in a small computer.

Dolby, Ray Milton (b. January 18, 1933): American. In 1966, Dolby invented the Dolby A-type noise reduction, a system that suppresses background noise.

Dollond, John (1706-1761): English. An optician, Dollond eliminated the color fringe in refracting telescopes with his invention of the achromatic lens, patented in 1758.

Donkin, Bryan (1768-1855): English. In 1813, Donkin patented a rotary press whose composition ink rollers, made of glue and molasses, were an influential innovation.

Donovan, Marion (October 15, 1917-November 4, 1998): American. Donovan simplified laundry chores by inventing a waterproof diaper, the Boater, patented in 1951, and disposable version soon after.

Dow, Herbert Henry* (February 26, 1866-October 15, 1930): American. Dow's method for extracting bromine cheaply from brine by electrolysis set the stage for a great expansion in the American chemical industry, particularly through Dow Chemical Company, founded in 1895.

Dragomir, Anastase (1896-1966): Romanian. Dragomir's "parachute cell," tested in 1929, was a prototype of the aircraft ejection seat.

Drais, Karl (April 29, 1785-December 10, 1851): German. In 1813, Drais built a four-wheel carriage powered by human pedalers, and in 1817 he tested his two-wheel velocipede (also known as a hobby horse), the ancestor of the modern bicycle.

Draper, Charles Stark* (October 2, 1901-July 25, 1987): American. Draper is widely known as the "father of inertial navigation" because his system, based upon gyroscopes and accelerometers, senses directional change on its own and has been used in submarines, missiles, aircraft, and spacecraft.

Drebbel, Cornelius (1572-November 7, 1633): Dutch. Drebbel is credited with constructing the first navigable submarine about 1621. Oar-powered, it operated at about four meters depth.

Drew, Charles Richard* (June 3, 1904-April 1, 1950): American. Drew revolutionized the storage of blood through his method of separating plasma from whole blood and dehydrating it. The technique produced large quantities of transfusible blood for the wounded during World War II.

Drew, Richard G.* (June 22, 1899-December 14, 1980): American. Drew invented the first paper-backed masking tape in 1925 and five years later the first transparent cellophane Scotch tape.

Drinker, Philip (December 12, 1894-October 19, 1972): American. With Louis Agassiz Shaw, Drinker invented the iron lung to make it easier for people with forms of paralysis, such as polio, to breathe. It was successfully tested on a patient in 1928.

Duggar, Benjamin Minge (September 1, 1872-September 10, 1956): American. In 1948, Duggar isolated the commercially viable broad-spectrum antibiotic aureomycin from fungus.

Dunlop, John Boyd* (February 5, 1840-October 23, 1921): Scottish. In 1888, Dunlop invented the pneumatic tire in an attempt to make his son's tricycle more comfortable to ride.

Dunwoody, Henry Harrison Chase (October 23, 1842-January 1, 1933): American. A brigadier general in the U.S. Army Signal Corps, Dunwoody received a patent for the carborundum crystal detector, an early form of the radio, in 1906, developing it with Greenleaf W. Pickard.

Durant, Graham John (b. March 14, 1934): English. With John Emmett and Charon Ganellin, Durant discovered the H2 receptor class of drugs, including the acid-inhibitor cimetidine (Tagamet, patented in 1976).

Duryea, Charles Edgar (December 15, 1861-September 28, 1938): American. Assisted by his younger brother James Frank, Duryea built the first successful American automobile with a gasoline engine in 1893.

Dyson, James (b. May 2, 1947): English. Dyson's G-Force, the first bagless vacuum cleaner, went on sale in Japan in 1986, and his better-known Dual Cyclone entered the market in England in 1993.

E

Eames, Charles and Ray (June 17, 1907-August 21, 1978 [Charles]; December 15, 1912-August 21, 1988 [Ray]): American. Both architects, this married couple built Eames House in 1949, a prototype of the modern, space-efficient prefabricated house.

Eastman, George* (July 12, 1854-March 14, 1932): American. Eastman greatly simplified photography, first with mass-produced dry glass photographic plates in 1880 and then with celluloid roll film in 1889.

Eckert, John Presper* (April 9, 1919-June 3, 1995): American. Working with John William Mauchly, Eckert built the first general-purpose electronic digital computer, ENIAC, in 1946 and the first commercial model, UNIVAC, in 1951.

Edgerton, Harold E.* (April 6, 1903-January 4, 1990): American. "Doc" Edgerton invented the gas flash bulb in 1928 and in 1931 synchronized a stroboscope with a camera, which permitted ultra-high-speed and stop-action photography.

Edison, Thomas Alva* (February 11, 1847-October 18, 1931): American. America's most famous inventor opened his Menlo Park laboratory in 1876 and produced the light bulb, improved stock ticker, motion-picture projector, and phonograph, among many other innovations.

Ehrlich, Paul (March 14, 1854-August 14, 1915): German. Ehrlich received the 1908 Nobel Prize in Physiology or Medicine for inventing Salvarsan (arsphenamine), the "magic bullet" that cured syphilis.

Eich, Brendan (b. July 4, 1964): American. In 1995, Eich created the scripting language JavaScript for World Wide Web applications.

Einhorn, Alfred (1856-1917): German. Einhorn synthesized Novocain in 1905 to replace cocaine as an anesthetic.

Einstein, Albert* (March 14, 1879-April 18, 1955): German American. With Leo Szilard in 1930, Einstein patented an electric refrigerator using ammonia, butane, and water in the heat-exchange process. Never marketed, the design attracted renewed attention in the twenty-first century as less harmful to the environment than existing machines.

Einthoven, Willem* (May 21, 1860-September 28, 1927): Dutch. In 1903, Einthoven developed the string galvanometer (forerunner of the electrocardiogram), which affords a sensitive, visual record of the heart's action. He received the 1924 Nobel Prize in Physiology or Medicine for it.

Elion, Gertrude Belle* (January 23, 1918-February 21, 1999): American. Elion synthesized a purine-based compound that checks the growth of leukemia cells, for which she shared the 1988 Nobel Prize in Physiology or Medicine.

Elmqvist, Rune (December 1, 1906-December 15, 1996): Swedish. Elmqvist devised a rechargeable, implantable cardiac pacemaker in 1958.

Elster, Julius (1854-1920): German. With Hans Friedrich Geitel, in 1904 Elster built a photoelectric cell consisting of a vacuum tube with a cathode and anode.

Emeagwali, Philip* (b. August 23, 1954): Nigerian American. In addition to helping launch the Internet, Emeagwali invented a method to track oil flow underground using a supercomputer.

Engelbart, Douglas C. (b. January 30, 1925): American. Engelbart revolutionized the human-computer interface with his invention of the computer mouse, hypertext, and groupware.

Ericsson, John* (July 31, 1803-March 8, 1889): Swedish American. Among Ericsson's many nautical innovations were the screw propeller and the *Monitor*, the first ironclad warship.

Ericsson, Lars Magnus (May 5, 1846-December 17, 1926): Swedish. Ericsson's designs for telephones and telephone exchanges, including the first multideck unit in the 1880's, were imitated by companies worldwide.

Espenschied, Lloyd (April 27, 1889-June 1, 1986): American. As well as developing the coaxial cable with Herman Affel, Espenschied patented a collision-avoidance system for trains and a radio altimeter for airplanes.

Evans, Oliver* (September 13, 1755-April 15, 1819): American. Evans refined the high-pressure steam engine, applied his design to power a flour mill, and received the first American patent for a steam-powered vehicle.

Evinrude, Ole (April 19, 1877-July 12, 1934): Norwegian American. Evinrude introduced the first commercially practical outboard motor in 1909. It had a single cylinder and produced 1.5 horsepower.

F

Face, Samuel (1923-2001): American. Face developed concrete leveling technology that became the industry standard and invented the Lightning Switch, a wireless light switch.

Factor, Max (1877-August 30, 1938): Polish American. World renowned for his cosmetic company, Factor adapted makeup for the movies and invented lip gloss in 1930 and Pan-Cake makeup in 1937.

Fadell, Tony* (b. 1969): American. Fadell conceived of the iPod music and video player as an independent businessman, and in 2001 Apple Computer hired him to lead the team developing it.

Faget, Maxime (August 26, 1921-October 9, 2004): American. Faget designed the Mercury space capsule for the National Aeronautics and Space Administration (NASA), first launched in 1961, and contributed to the design of the Gemini and Apollo capsules and the space shuttle.

Faggin, Federico* (b. December 1, 1941): Italian American. Faggin invented the metal-oxide-semiconductor (MOS) silicon gate technology, which became the basis for most computer chip designs, and later helped develop the first microprocessor, the Intel 4004.

Fahrenheit, Daniel Gabriel* (May 24, 1686-September 16, 1736): German. Fahrenheit invented the mercury thermometer in 1714 and the temperature scale that bears his name.

Faraday, Michael* (September 22, 1791-August 25, 1867): English. Besides contributing to the fundamental understanding of electromagnetism, Faraday invented the electric transformer, generator, and motor.

Farina, Johann Maria (December 8, 1685-November 25, 1766): Italian German. In 1709, Farina invented Eau de Cologne, whose citrus-based fragrance marked a departure from earlier, sweeter perfumes.

Farmer, Moses G. (February 9, 1820-May 25, 1893): American. With William F. Channing, in 1851 Farmer installed the first electric fire alarm system in Boston.

Farnsworth, Philo T.* (August 19, 1906-March 11, 1971): American. In 1927, Farnsworth was the first to achieve an all-electronic transmission of images with his image dissector.

Feinbloom, William (1903-1985): American. An optometrist, in 1937 Feinbloom patented a lightweight glass-plastic contact lens.

Fergason, James* (January 12, 1934-December 9, 2008): American. Fergason built the first operating liquid crystal display (LCD), demonstrated in 1971, and led the development of the technology.

Fermi, Enrico* (September 29, 1901-November 28, 1954): Italian American. As well as his foundational work in radiation physics, for which he received the 1938 Nobel Prize in Physics, Fermi designed and oversaw the construction of the first nuclear reactor in 1942.

Fernández-Morán, Humberto (February 18, 1924-March 17, 1999): Venezuelan. Fernández-Morán invented the diamond scalpel and pioneered cryoultramicrotomy, both means to slice tissue for examination by electron microscope.

Fessenden, Reginald Aubrey* (October 6, 1866-July 22, 1932): Canadian. Fessenden made the first two-way transatlantic radio transmission in 1906 and invented the heterodyne circuit and the radio compass.

Fick, Adolf Eugen (September 3, 1829-August 21, 1901): German. In 1887, Fick produced the first successful contact lens, made of heavy brown glass.

Fihri, Fatima al- (fl. mid-ninth century): Moroccan. Al-Fihri founded the University of Al-Qarawiyin in 859 said to be the first degree-granting university and still in operation.

Firestone, Harvey Samuel (December 20, 1868-February 7, 1938): American. The Firestone Tire and Rubber Company, established in 1900, was the first to cater to the automobile industry, first with solid rubber tires and then with Firestone's specially developed pneumatic rubber tires.

Fischer, Artur (b. December 31, 1919): German. Among Fischer's more than one thousand patents are the Photo Flash Light, a threaded plug for inserting a screw into a wall, and the construction toy fischertechnik.

Fischer, Rudolph (1881-1957): German. In 1911, Fischer patented a photographic film of three layers, each producing a different color when developed. It was later sold as Agfacolor.

Fisher, Alva J. (1862-1947): American. Fisher invented Thor, an early electric-powered washing machine, first marketed in 1908.

Fitch, John* (January 21, 1743-July 2, 1798): American. Fitch is credited with building the first successful steamboat, launched in August, 1787. It had six paddles on each side, propelling it like a canoe.

Flanigen, Edith (b. January 28, 1929): American. Beginning in 1956, Flanigen developed numerous synthetic molecular sieves from zeolites. They are used in the chemical and petroleum industries for producing products such as gasoline and oxygen and cleaning up nuclear waste.

Fleming, Alexander (August 6, 1881-March 11, 1955): Scottish. Fleming received the 1945 Nobel Prize in Physiology or Medicine for discovering in 1928 that penicillin prevented the growth of staphylococci, a discovery that led to a revolution in medical treatment with antibacterial drugs.

Fleming, John Ambrose (November 29, 1849-April 18, 1945): English. In 1904, Fleming patented his thermionic tube, later known as the two-electrode radio rectifier, or vacuum diode. Capable of detecting high-frequency signals, it was an important step in the development of radio.

Fleming, Sandford (January 7, 1827-July 22, 1915): Scottish Canadian. A civil engineer, Fleming first proposed standard time with time zones and designed Canada's first postage stamp.

Flowers, Tommy (December 22, 1905-October 28, 1998): English. Flowers designed Colossus, an early electronic computer. The one-ton, room-sized machine was completed in 1943.

Focke, Heinrich (October 8, 1890-February 25, 1979): German. A pioneer in fighter plane design, Focke also invented the twin-rotor helicopter, which first flew in 1936.

Fogarty, Thomas J. (b. February 25, 1934): American. In 1969, Fogarty, a cardiovascular surgeon, patented his balloon catheter, used to clear clogged blood vessels.

Fokker, Anthony Herman Gerard (April 6, 1890-December 23, 1939): Dutch American. A designer of fighter planes in World War I, Fokker invented an interrupter gear, which enabled a machine gun to fire past a plane's spinning propeller.

Ford, Henry* (July 30, 1863-April 7, 1947): American. The most famous name in the American automobile industry, Ford completed the Quadricycle, his first self-propelled vehicle, in 1896, and founded Ford Motor Company in 1903. His Model T, introduced in 1908, quickly dominated the market.

Forrester, Jay Wright* (b. July 14, 1918): American. Forrester built Whirlwind, a high-speed general-purpose digital computer that became operational in 1951. It was the first to use magnetic core memory.

Foucault, Léon* (September 18, 1819-February 11, 1868): French. A brilliant experimental physicist, Foucault fabricated the first gyroscope in 1852 in order to demonstrate that Earth rotates.

Fourneyron, Benoît (October 31, 1802-July 31, 1867): French. Fourneyron constructed the first water turbine in 1827, which had six horsepower. His larger, more efficient turbines powered many factories in the early Industrial Revolution.

Fowler, John (July 11, 1826-December 4, 1864): English. Fowler constructed the first steam-powered plow in 1852. It was dragged across a field as the engine turned a winch that pulled on an anchored cable.

Franklin, Benjamin* (January 17, 1706-April 17, 1790): American. Besides helping to establish the United States, Franklin is well known for inventing the Franklin stove, bifocals, the lightning rod, and the odometer.

Franz, John E. (b. December 21, 1929): American. Franz synthesized glyphosate in 1970. This broad-spectrum herbicide kills weeds after they grow, and so its use does not entail topsoil loss and the expense of tillage.

Fraunhofer, Joseph von* (March 6, 1787-June 7, 1826): German. Fraunhofer's method for measuring the index of refraction in glass improved optical quality; he also invented diffraction grating, which scatters white light into various wavelengths.

Free, Helen M.* (b. February 20, 1923): American. With her husband, Alfred H. Free, Free developed the swift "dip-and-read" urine test for glucose, used to monitor diabetes.

Frenkiel, Richard Henry (b. March 4, 1943): American. With Joe S. Engel, Frenkiel led the team at Bell Labs that during the 1960's devised basic cellular phone system architecture.

Fresnel, Augustin-Jean (May 10, 1788-July 14, 1827): French. Drawing from his wave theory of light, Fresnel invented the Fresnel lens, a lightweight design with large aperture and short focal length that became widely used in lighthouses.

Fry, Art (b. August 19, 1931): American. Fry's Post-it notes, developed with Spencer Silver and first marketed by the Minnesota Mining and Manufacturing Company (3M) in 1977, soon became as ubiquitous in office work as the stapler and the paper clip.

Fry, Joseph (1795-1879): English. Fry is credited with producing the first commercial candy bar in 1847.

Fuller, Calvin* (May 25, 1902-October 28, 1994): American. Fuller was among the coinventors of the first efficient silicon solar cell.

Fuller, R. Buckminster* (July 12, 1895-July 1, 1983): American. The epitome of the modern Renaissance man, Fuller was above all things as a visionary inventor, and his best-known innovations were the Dymaxion omnidirectional car (1932) and the geodesic dome (1947).

Fulton, Robert* (November 14, 1765-February 24, 1815): American. Fulton demonstrated the reliability of steam navigation when he and Robert R. Livingston sailed the steamboat *Clermont* from New York City to Albany on the Hudson River in 1807.

Funk, Casimir (February 23, 1884-November 20, 1967): Polish American. Funk discovered that a deficiency of amines led to certain diseases, such as scurvy and rickets. He called these vital amines "vitamines," later shortened to vitamins.

Fyodorov, Svyatoslav (August 8, 1927-June 2, 2000): Russian. Fyodorov originated radial keratotomy in 1974, a surgical procedure to correct myopia with incisions near the cornea of the eye.

G

Gabe, Frances (b. 1915): American. Gabe built the self-cleaning house, whose rooms, sink, shower, toilet, and bathtub are washed with jets of soapy water, drained, and dried with a blower, all operated with push-button controls.

Gabor, Dennis* (June 5, 1900-February 8, 1979): Hungarian British. Gabor received the 1971 Nobel Prize in Physics for his invention of holography—three-dimensional, lensless imaging.

Gadgil, Ashok* (b. 1950): Indian. In 1996, Gadgil produced his UV Waterworks, a technology that disinfects drinking water and is inexpensive and effective enough to use widely in developing countries.

Galileo* (February 15, 1564-January 8, 1642): Italian. Many scholars believe that Galileo established the modern form of scientific experimentation, but he also invented practical devices, such as the water thermometer in 1593 and a horse-powered pump in 1594.

Galitzine, Boris Borisovich (March 2, 1862-May 17, 1916): Russian. Galitzine built the first electromagnetic seismograph in 1906 and was a founder of the scientific discipline seismology.

Gallo, Robert Charles* (b. March 23, 1937): American. Besides codiscovering the human immunodeficiency virus (HIV) with Luc Montagnier, Gallo developed a blood test to detect it.

Galvani, Luigi (September 9, 1737-December 4, 1798): Italian. An anatomist studying frogs, Galvani discovered that a muscle contracts when its associated nerves touch certain metals. This galvanism (current electricity) inspired Alessandro Volta to invent the battery.

Garand, John (January 1, 1888-February 16, 1974): Canadian American. Garand designed the M1 semiautomatic rifle, the mainstay of American ground forces during World War II.

Gates, Bill* (b. October 28, 1955): American. Gates was one of the inventors of the basic operating system that underlies personal computer software and cofounded Microsoft Corporation.

Gates, Elmer R. (1859-1923): American. A versatile inventor for both home and industry, Gates is best known for his foam fire extinguisher.

Gatling, Richard* (September 12, 1818-February 26, 1903): American. Gatling designed the hand-cranked Gatling gun, capable of firing 350 bullets per minute, during the Civil War, although the U.S. Army did not use it until later.

Gay-Lussac, Joseph-Louis* (December 6, 1778-May 9, 1850): French. Gay-Lussac made significant advances in industrial and analytic chemistry and invented techniques and apparatuses for the production and study of chemicals.

Geiger, Hans* (September 30, 1882-September 24, 1945): German. The Geiger counter (1908) detects the alpha particles (positive ions) emitted during radioactive decay. It was widely used by prospectors searching for uranium ore.

Geissler, Heinrich (May 26, 1815-January 24, 1879): German. The Geissler tube, invented in 1857, contains low-pressure gas that glows when high voltage is applied to the electrodes on either end.

Germer, Edmund (August 24, 1901-August 10, 1987): German American. Germer improved the efficiency of lighting with his inventions of the fluorescent lamp (patented in 1926 with Friedrich Meyer and Hans Spanner) and the high-pressure mercury-vapor lamp.

Getting, Ivan A.* (January 18, 1912-October 11, 2003): American. Getting originated and advocated the development of the Global Positioning System (GPS), used by the military and civilians for pinpointing location.

Giannini, Amadeo Peter (May 6, 1870-June 3, 1949): American. Following the 1906 San Francisco earthquake, Giannini launched a shoestring bank that extended loans to small businesses and individuals from branch banks. His innovation in consumer banking grew into Bank of America, the nation's largest.

Giauque, William Francis* (May 12, 1895-March 28, 1982): Canadian American. Giauque received the 1949

Nobel Prize in Chemistry for his experiments in ultralow temperatures using adiabatic demagnetization refrigeration.

Gibbon, John Heysham (September 29, 1903-February 5, 1973): American. In 1935, Gibbon, a surgeon, kept a cat alive with an external pump acting as an artificial heart, and in 1953 he successfully used his heart-lung machine during open-heart surgery on a person.

Giffard, Henri (1825-1882): French. Giffard built the first powered, steerable airship in 1852: a 144-foot long, hydrogen-filled balloon propelled by a propeller and three-horsepower steam engine.

Gilbreth, Lillian Evelyn* (May 24, 1878-January 2, 1972): American. Gilbreth was among the first organizational psychologists and a pioneer in industrial engineering.

Gillette, King Camp* (January 5, 1855-July 9, 1932): American. With William Nickerson, Gillette developed his safety razor in 1903 with a blade intended to be used and thrown away, thus supporting steady sales.

Ginsburg, Charles P.* (July 27, 1920-April 9, 1992): American. With Ray Dolby, Ginsburg constructed the first practical magnetic videotape recorder in 1956.

Glaser, Donald A.* (b. September 21, 1926): American. Glaser's ether-filled bubble chamber, for which he received the 1960 Nobel Prize in Physics, revolutionized nuclear physics, enabling scientists to detect short-lived subatomic particles.

Glidden, Joseph* (January 18, 1813-October 9, 1906): American. Glidden patented his invention, two-stranded barbed wire, in 1874. It became the most popular fencing for Western farms and ranchland.

Gobyato, Leonid (1875-1915): Russian. With Roman Kondratenko, Gobyato built and used the first portable mortar during the defense of Port Arthur in the 1904 Russo-Japanese War.

Goddard, Robert H.* (October 5, 1882-August 10, 1945): American. Widely held to be the father of rocket science, Goddard launched the first liquid-fuel rocket in 1923.

Goddard, William A. (July 10, 1913-September 29, 1997): American. In 1955, Goddard, John Lynott, and Louis Stevens developed a computer memory system of stacked magnetized disks on a rotating shaft with detached read-write heads: a magnetic disk drive.

Godowsky, Leopold, Jr.* (May 27, 1900-February 18, 1983): American. A professional violinist and amateur photographer, Godowsky and Leopold Mannes, another musician, invented the process for producing Kodachrome color transparency film, patented in 1935.

Goldman, Sylvan (November 15, 1898-November 25, 1984): American. A grocer, Goldman conceived of the shopping cart in 1936 and introduced it a year later for the convenience of shoppers at his Standard-Humpty Dumpty supermarkets.

Goldmark, Peter Carl* (December 2, 1906-December 7, 1977): Hungarian American. Goldmark invented the 33⅓ revolutions-per-minute long-playing (LP) phonograph record, introduced in 1948.

Goodyear, Charles* (December 29, 1800-July 1, 1860): American. In 1844, Goodyear patented his process for the vulcanization of rubber: curing by heating natural rubber mixed with sulfur.

Gore, Robert W. (b. 1939): American. Gore synthesized a new form of polytetrafluorethylene (PTFE) and found it was perfect for making a sturdy fabric. It was marketed as GORE-TEX in 1976.

Gould, Gordon* (July 17, 1920-September 16, 2005): American. Gould coined "laser" as an acronym for "light amplification by stimulated emission of radiation," a process he formulated independently of Theodore Harold Maiman, who built the first device.

Gourdine, Meredith C.* (September 26, 1929-November 20, 1998): American. Gourdine was a pioneer in electrogasdynamics—the action of charged particles through a gas—and applied it in practical inventions for energy conversion, spraying systems, and pollution control.

Gower, Richard Hall (1768-1833): English. Gower was a naval architect who invented a novel concave design for a ship's prow, an instrument for measuring a ship's speed, a speaking tube to lower decks, and a floating anchor.

Graham, Bette Nesmith* (March 23, 1924-May 12, 1980): American. A secretary, in 1951 Graham began painting white tempera over typewriter mistakes in order to make corrections. She began bottling her Mistake Out in 1956 and patented it as Liquid Paper a year later.

Gramme, Zénobe (April 4, 1826-January 20, 1901): Belgian. Gramme introduced the Gramme dynamo in 1869, a continuous-current electrical generator that was the first generator powerful enough to be used in industry.

Gray, Elisha* (August 2, 1835-January 21, 1901): American. Gray was among the developers of telegraphy and filed for a patent for the telephone on the same day as Alexander Graham Bell.

Greatbatch, Wilson* (b. September 6, 1919): American. Greatbatch developed an implantable heart pacemaker and a corrosion-free lithium-iodide battery to power it.

Greene, Leonard Michael (June 8, 1918-November 30, 2006): American. Greene invented a device to warn pilots that their planes were about to stall and another to detect wind shear; both saved many lives.

Greenwood, Chester (December 4, 1858-July 5, 1937): American. To protect his ears while he was testing new ice skates in 1873, Greenwood invented thermal earmuffs.

Gregory, James* (November, 1638-October, 1675): Scottish. Gregory designed the first practical reflecting telescope.

Gross, Alfred J.* (February 22, 1918-December 21, 2000): Canadian American. A visionary in mass communications, Gross developed many modern electronic devices, such as the walkie-talkie and the pager.

Grove, Sir William Robert* (July 11, 1811-August 1, 1896): English. Grove devised two new kinds of electrical batteries: the nitric acid battery and the gas battery.

Grumman, Leroy (January 4, 1895-October 4, 1982): American. Grumman cofounded Grumman Aerospace Corporation and patented a retractable landing gear for airplanes in 1932.

Guérin, Camille (December 22, 1872-June 9, 1961): French. With Albert Calmette, in 1921 Guérin developed bacillus Calmette-Guérin (BCG), a vaccine against tuberculosis.

Guericke, Otto von* (November 20, 1602-May 11, 1686): German. Von Guericke investigated the nature of atmospheric pressure and invented a vacuum pump.

Gundlach, Robert (b. September 7, 1926): American. As a research scientist for the Haloid Company (later Xerox Corporation), Gundlach made innovations to the photocopier that made it more versatile and easier and cheaper to use.

Gürsu, Hakan (b. 1959): Turkish. Gürsu designed the *Volitan*, a boat powered by both wind and solar energy.

Gutenberg, Johann* (1394-1399-Probably February 3, 1468): German. Gutenberg invented a printing press with metal movable type, reducing the cost of books and fostering a burgeoning of literacy.

Guthrie, Samuel (1782-October 19, 1848): American. Guthrie was the first American to synthesize chloroform, which he did in 1831 independently of European researchers.

H

Haber, Fritz* (December 9, 1868-January 29, 1934): German. Haber received the 1918 Nobel Prize in Chemistry for developing artificial nitrogen-bearing fertilizers, which expanded global agricultural production.

Hadley, John (April 16, 1682-February 14, 1744): English. In 1731, Hadley, a mathematician, published a description of his octant, which could be used to measure the height of the Sun above the horizon at sea in order to calculate a ship's latitude.

Haffkine, Waldemar (March 15, 1860-October 25, 1930): Russian Swiss. Haffkine discovered the principle of inoculation with a weakened form of a pathogen, with which he developed anticholera (1892) and antiplague (1896) vaccines.

Haldane, T. G. N. (December 14, 1897-June 24, 1981): English. In 1927, Haldane became the first person to patent a heat pump, which cools by transferring heat, usually by means of a cold fluid.

Hall, Charles Martin* (December 6, 1863-December 27, 1914): American. Large-scale aluminum production became possible after Hall found a way to produce pure metallic aluminum from ore by electrolysis.

Hall, H. Tracy* (October 20, 1919-July 25, 2008): American. Hall invented the method for producing synthetic diamond, which has many applications in industry, electronics, and jewelry.

Hall, Joyce C. (August 29, 1891-October 29, 1982): American. Hall founded Hall Brothers (later Hallmark) in 1910, commercializing greeting cards and helping make them a major form of personal communication.

Hall, Lloyd Augustus (June 20, 1894-January 2, 1971): American. Hall developed an improved process for curing and preserving foods with salts in 1925 and later a way to sterilize foods with ethylene oxide gas.

Hall, Robert N. (b. December 25, 1919): American. Hall built the first semiconductor injection laser in 1962, now widely used in compact disc (CD) players, printers, and optical fiber communications.

Hall, Thomas Seavey (April 1, 1827-December 1, 1880): American. In 1869, Hall invented the banjo signal, which warns when more than one train is on the same track, and other railroad safety devices during the 1860's and 1870's.

Hallidie, Andrew (March 16, 1836-April 24, 1900): English American. In 1873, Hallidie built the world's first cable car system in San Francisco, California.

Hamilton, William (August 4, 1805-September 2, 1865): Irish. A leading mathematical physicist of the nineteenth century, Hamilton is best known for introducing quaternions in 1843, a number system used in calculations involving three-dimensional rotations.

Hammond, John Hays, Jr. (April 13, 1888-February 12, 1965): American. Of his more than one hundred patents, Hammond's best known is a radio-operated remote-control system (1914).

Hancock, Thomas (May 8, 1786-March 26, 1865): English. With his "masticator" (1821), Hancock could produce shredded rubber for forming into blocks or sheets. He is credited with founding the British rubber industry.

Hanford, William Edward (December 9, 1908-January 27, 1996): American. Hanford and Donald Fletcher Holmes developed the process of synthesizing polyurethane, patented in 1942.

Hargreaves, James* (January 8, 1720 [baptized]-April 22, 1778): English. Hargreaves's spinning jenny was among the first devices in the industrialization of the textile industry.

Harington, Sir John* (1561-November 20, 1612): English. A member of the Elizabethan literati, Harington was the first person to describe a workable flush toilet (1596).

Harrison, John* (March, 1693-March 24, 1776): English. Harrison constructed the first marine chronometer that could keep time accurately at sea, a development crucial to finding the longitude for navigation.

Hasselblad, Victor (March 8, 1906-August 5, 1978): Swedish. Hasselblad released the civilian version of a 6-by-6-centimeter single-lens reflex camera in 1948; one of its descendants went to the Moon with Apollo 11.

Hayes, Dennis (b. 1950): American. In 1977, Hayes and Dale Heatherington produced the modulator-demodulator for personal computers (PC modem) for converting data to a form transmissible by telephone line.

Heaviside, Oliver* (May 18, 1850-February 3, 1925): English. An innovative mathematical physicist, Heaviside also invented the distortionless transmission line for telegraph and telephone cables.

Heilman, M. Stephen (b. December 25, 1933): American. Heilman coinvented the implantable heart defibrillator, which detects and corrects deadly errant heart rhythms.

Hell, Jozef Karol (1713-1789): Hungarian. Hell's water pillar, invented in 1749, could pump water up from depths of more than two hundred meters.

Helmholtz, Hermann von* (August 31, 1821-September 8, 1894): German. Helmholtz invented the ophthalmoscope for seeing into the eye and the ophthalmometer for measuring its curvature.

Henry, Beulah Louise* (September 28, 1887-February, 1973): American. Among Henry's numerous inventions are the vacuum ice cream freezer, children's toys, and improvements to typewriters and sewing machines.

Henry, Joseph* (December 17, 1797-May 13, 1878): American. An early master of electrical experiments, Henry invented an electric motor and the electromagnetic relay used in telegraphy.

Hero of Alexandria* (Before 62-c. 100 C.E.): Greek. Hero produced a novel surveying instrument, catapult, and coin-operated water dispenser but is best known for inventing the aeolipile, a precursor of the steam engine.

Hertz, Heinrich* (February 22, 1857-January 1, 1894): German. Hertz constructed the first radio transmitter and receiver and investigated the wave properties of electromagnetic radiation and the photoelectric effect.

Hevesy, George de (August 1, 1885-July 5, 1966): Hungarian. As well as codiscovering the element hafnium, von Hevesy received the 1943 Nobel Prize in Chemistry for developing radioactive tracer analysis, used in chemistry and medicine.

Hewitt, Peter Cooper* (May 5, 1861-August 25, 1921): American. Hewitt devised a bright, energy-efficient mercury-vapor lamp, which became a common source of industrial lighting.

Hewlett, William Redington* (May 20, 1913-January 12, 2001): American. Cofounder of the Hewlett-Packard Company, Hewlett invented the audio oscillator, which was the company's first successful product.

Higinbotham, William A. (October 25, 1910-November 10, 1994): American. In 1958, Higinbotham invented one of the first computer games, Tennis for Two.

Highs, Thomas (1718-1803): English. Highs produced an early version of the spinning jenny in 1764.

Higonnet, Rene Alphonse (April 5, 1902-October 13, 1984): French. With Louis Marius Moyroud, Higonnet built the first practical phototypesetting machine in 1946.

Hill, Rowland (December 3, 1795-August 27, 1879): English. In his *Post Office Reform* (1837), Hill argued for adhesive postage stamps to demonstrate prepayment of postage by the sender. England's Post Office brought out the first stamps four years later.

Hilleman, Maurice Ralph (August 30, 1919-April 11, 2005): American. Hilleman created dozens of vaccines for some of the deadliest human diseases, including influenza, hepatitis A and B, measles, and meningitis.

Hillier, James* (August 22, 1915-January 15, 2007): Canadian. With Albert Prebus, Hillier built a successful high-resolution electron microscope in 1938, the first in the United States.

Hodgkin, Dorothy Crowfoot* (May 12, 1910-July 29, 1994): English. An expert in X-ray crystallography, Hodgkin received the 1964 Nobel Prize in Chemistry for defining the structure of cholesterol, penicillin, vitamin B_{12}, and insulin.

Hoe, Richard March* (September 12, 1812-June 7, 1886): American. Hoe's rotary printing presses produced newspapers so quickly that they facilitated modern mass-produced journalism.

Hoff, Ted* (b. October 28, 1937): American. Hoff developed the microprocessor: the entire circuitry for a computer's central processing unit (CPU) on a single chip.

Hoffmann, Felix (January 21,1868-February 8, 1946): German. In 1897, Hoffman synthesized acetyl salicylic acid (aspirin), which Bayer first distributed to doctors as a pain reliever two years later.

Hogan, Paul (b. August 7, 1919): American. In 1951, Hogan and Robert Banks invented crystalline and high-density polyethylene (HDPE), plastics since used in common products such as milk jugs and indoor-outdoor carpeting.

Holland, John Philip* (February 29, 1840-August 12, 1914): Irish American. Holland designed and oversaw construction of the USS *Holland*, the first submarine commissioned by the U.S. Navy.

Hollerith, Herman* (February 29, 1860-November 17, 1929): American. Hollerith's punch-card tabulating machine, and associated sorting and counting devices, proved invaluable to governments and businesses after their successful use in the 1890 census.

Holley, Alexander (July 20, 1832-January 29, 1882): American. Holley made improvements in Sir Henry Bessemer's steelmaking process, opening the first of many steel factories in 1865.

Holly, Birdsill, Jr. (November 8, 1820-April 27, 1894): American. A holder of some 150 patents, Holly is best known for his fire protection system, which included a steam engine, a rotary water pump, and the fire hydrant.

Holonyak, Nick, Jr.* (b. November 3, 1928): American. Holonyak invented the first practical light-emitting diode, the first visible-spectrum laser, and the light-dimmer switch, also coinventing the transistor laser.

Holt, Benjamin (January 1, 1849-December 5, 1920): American. In 1890, Holt successfully tested a steam-powered tractor, naming a later model the Caterpillar.

Hood, Leroy E. (b. October 10, 1938): American. Hood is renowned for the automatic DNA sequencer, with which the entire genome of a human being was decoded in 2003.

Hooke, Robert* (July 18, 1635-March 3, 1703): English. In charge of devising demonstration experiments for England's Royal Society, Hooke innovated broadly in science theory and equipment. Among his many inventions were a balance wheel, universal joint, iris diaphragm, and air pump.

Hoover, Erna Schneider* (b. June 19, 1926): American. Hoover made possible modern telecommunications with her computerized switching system that can process a high volume of calls.

Hopkins, Samuel (1743-1818): American. Hopkins patented an improved method for making potash, for which he acquired the first patent granted under the United States' Patent Act of 1790.

Hopper, Grace Murray* (December 9, 1906-January 1, 1992): American. A U.S. naval officer, Hopper developed the COBOL computer programming language and a variety of innovative software.

Hopps, John Alexander* (1919-November 24, 1998): Canadian. Hopps laid the foundation for the cardiac pacemaker when he became the first person to stimulate a failing heart with electric current.

Hornby, Frank (1863-1936): English. A pioneering toy manufacturer, Hornby introduced a construction toy (Meccano), chemistry set (Kemex), electrical kit (Elektron), and model vehicles.

Houdry, Eugene (April 18, 1892-July 18, 1962): French American. In 1927, Houdry discovered a process for catalytically cracking low-grade crude oil into high-test gasoline.

Hounsfield, Godfrey Newbold* (August 28, 1919-August 12, 2004): English. Hounsfield shared the 1979 Nobel Prize in Physiology or Medicine for designing and building the first computerized axial tomography (CAT) scanner.

Howe, Elias* (July 9, 1819-October 3, 1867): American. Howe was the first American to build and patent a workable sewing machine.

Huangdi* (c. 2704-c. 2600 B.C.E.): Chinese. A figure of legendary stature, Huangdi is credited with introducing the horse-drawn chariot, ceramics, military armor, and agricultural calendar.

Hubert, Conrad (1855-March 14, 1928): Russian American. In the late 1890's, Hubert and David Misell developed a small electric lamp and a battery to power it, the genesis of the tubular flashlight. Their company later became Eveready.

Hughes, David Edward* (May 16, 1831-January 22, 1900): English. Hughes's carbon microphone was important to the development of the telephone, and he invented a telegraph printer.

Hughes, Howard R. (September 9, 1869-January 14, 1924): American. In 1909, Hughes, father of the famed aviator and movie director, obtained patents for the two-cone rock drill bit that became standard on rotary drills.

Hulett, George (September 26, 1846-January 17, 1923): American. The Hulett unloader featured a bucket with a cantilevered arm for unloading ore and coal from vessels, greatly speeding the process.

Hülsmeyer, Christian (December 25, 1881-January 31, 1957): German. In 1904, Hülsmeyer demonstrated his telemobiloscope, a precursor to radar, which served as a collision-warning device aboard ships.

Hunt, Walter (July 29, 1796-June 8, 1859): American. Hunt invented many practical gadgets, such as a knife sharpener and a sewing machine, but he is best known for his safety pin, patented in 1849.

Hutchison, Miller Reese* (August 6, 1876-February 16, 1944): American. A chief engineer in Thomas Alva Edison's laboratory, Hutchison influenced numerous inventions and created others in communications, transportation, and military technology.

Huygens, Christiaan* (April 14, 1629-July 8, 1695): Dutch. Huygens developed an improved method for grinding telescope lenses, invented the pendulum clock, and proposed a wave theory of light.

Hyatt, John Wesley (November 28, 1837-May 10, 1920): American. Hyatt launched large-scale celluloid manufacturing with his discovery of a simplified production process in 1869 and his mastery of industrial management.

Hyde, Ida H.* (September 8, 1857-August 22, 1945): American. Hyde invented a microelectrode thin enough to be inserted into a single cell.

Hyde, J. Franklin (March 11, 1903-October 11, 1999): American. In 1934, Hyde created a way to make ultra-pure glass from fused silica, which found applications in spacecraft windows, telescopes, precision lenses, and optical fiber.

I

Ibuka, Masaru (April 11, 1908-December 19, 1997): Japanese. A cofounder of Sony Corporation, Ibuka led the team that produced the first transistor radio in 1955.

Iijima, Sumio* (b. May 2, 1939): Japanese. Iijima synthesized the first nanotubes in 1991, a basic advance in the development of nanotechnology.

Ilizarov, Gavril A. (June 15, 1921-July 24, 1992): Russian. The Ilizarov apparatus, patented in 1952, holds together a severed bone so that material can grow between the pieces, correcting deformities, a process called distraction osteogenesis.

Immink, Kees A. Schouhamer (b. December 18, 1946): Dutch. Schouhamer developed coding technologies for many modern consumer goods, such as the compact disc (CD), CD-ROM, digital video disc (DVD), and Blu-ray disc.

Ingersoll, Simon (March 3, 1818-July 24, 1894): American. Ingersoll's steam-powered rock drill, patented in 1871, was widely used in excavation, mining, and tunneling.

Inoue, Daisuke (b. May 10, 1940): Japanese. Inoue invented the karaoke machine in 1971, beloved by bar owners and amateur singers the world over.

J

Jābir ibn Ḥayyān, Abū Mūsā (Geber) (c. 721-c. 815): Arab. Geber is credited with urging the conversion of alchemy to an experimental science.

Jackson, Augustus (1808-unknown): American. Jackson improved the way to make ice cream in 1832 and developed new flavors, possibly during his tenure as a chef in the White House.

Jacobsen, Clayton II (b. 1932 or 1933): American. Jacobsen invented the Sea-Doo, a personal watercraft first sold in 1968 and then as the Jet Ski in 1973.

Jacquard, Joseph Marie (July 7, 1752-August 7, 1834): French. The Jacquard loom (1801) was the first to be programmable with punch cards.

Janney, Eli H. (November 12, 1831-June 16, 1912): American. Janney patented his knuckle-style automatic coupler for railroad cars in 1873.

Jansky, Karl G.* (October 22, 1905-February 14, 1950): American. While trying to rid an antenna of radio interference, Jansky discovered astronomical radio emissions, thus founding radio astronomy.

Janssen, Zacharias* (c. 1580-c. 1638): Dutch. An optician, Janssen developed a compound microscope and a telescope.

Jarvik, Robert* (b. May 11, 1946): American. Implanted in 1982, the Jarvik-7 became the first artificial heart to keep a terminally ill patient alive.

Javan, Ali* (b. December 26, 1926): Iranian American. Javan led a Bell Labs team that in 1960 built the helium-neon laser, the first gas laser and first continuous-light laser.

Jazarī, al-* (c. 1150-c. 1220): Arab. Al-Jazarī invented a suction pump and gears, levels, and values for water clocks and irrigation devices.

Jefferson, Thomas* (April 13, 1743-July 4, 1826): American. A versatile, practical scientist, the third U.S. president produced an improved ox plow, lap desk, and mechanical copier, as well as innovations in agriculture.

Jeffreys, Alec* (b. January 9, 1950): English. Jeffreys gave a powerful new tool to forensic science with his development of DNA profiling, also known as DNA fingerprinting, in 1984.

Jendrassik, György (May 13, 1898-February 8, 1954): Hungarian. In 1937, Jendrassik designed the Jendrassik Cs-1 turboprop, the prototype of engines used on many long-distance aircraft.

Jenkins, Charles Francis (August 22, 1867-June 6, 1934): American. Jenkins invented a mechanical scanning television and gave the first public television demonstration in the United States in 1925.

Jenner, Edward* (May 17, 1749-January 26, 1823): English. Jenner's great discovery, vaccination against disease, helped eradicate smallpox and started a revolution in public health.

Jennings, Thomas L.* (1791-February 11, 1859): American. Jennings's 1821 patent for a dry-cleaning technique to remove clothing stains was the first issued to an African American.

Jobs, Steve* (b. February 24, 1955): American. Jobs exerted a pervasive influence upon personal computing and consumer electronics as the cofounder and guiding spirit of Apple Computer from 1976 to 2009.

Joel, Amos Edward, Jr. (b. March 12, 1918): American. Developed in the 1960's, Joel's systems for switching cell phone service as the caller moves is the basis for modern telephone communications.

Johansson, Carl Edvard (March 15, 1864-September 30, 1943): Swedish. Johansson produced lengths of steel, called a gauge block set (patented in 1901), that provided exact standards of measurement and are widely used in machine shops and industry.

Johansson, Johan Petter (December 12, 1853-August 25, 1943): Swedish. In 1888, Johansson patented the pipe wrench and in 1892 the adjustable wrench.

Johnson, Clarence (February 27, 1910-December 21, 1990): American. As a leader in Lockheed's famous

Skunk Works, Johnson helped design some of the most advanced aircraft of his era, such as the U-2 and SR-71 spy planes.

Johnson, Edward H. (1846-1917): American. A business associate of Thomas Alva Edison, in 1882 Johnson became the first person to decorate a Christmas tree with electric lights.

Johnson, Eldridge R.* (February 18, 1867-November 14, 1945): American. With Emile Berliner, Johnson founded the Victor Talking Machine Company, the pioneering producer of phonographs and phonograph records.

Johnson, Herbert (fl. early twentieth century): American. In 1908, Johnson invented the standing electric mixer, originally intended for mixing bread dough.

Johnson, Lonnie G. (b. October 6, 1949): American. An engineer for the Air Force and Jet Propulsion Laboratory, Johnson invented the Super Soaker squirt gun in 1982.

Johnson, Nancy (c. 1795-1890): American. Credit for invention of the hand-cranked ice cream maker goes to Johnson, who patented one in 1843.

Jones, Amanda Theodosia (1835-1914): American. The Jones process, patented in 1873, is a method for preserving food by vacuum packing glass jars.

Jones, Frederick McKinley* (May 17, 1892-February 21, 1961): American. Jones created a ticket-dispensing machine, self-starting gas engine, starter generator, and vehicle air conditioner, among many other inventions.

Jones, Scott A. (b. 1960): American. Jones created voice mail in 1986 and founded the search engine ChaCha in 2006.

Judson, Whitcomb (1836-1909): American. Judson's "clasp locker" fastener, first exhibited in 1893, had hooks and eyes that were joined by a slide clasp: a precursor of the zipper.

Julian, Percy Lavon* (April 11, 1899-April 19, 1975): American. Julian, a chemist, produced several therapeutic drugs from plants, including the arthritis-relieving cortisone and the glaucoma medicine physostigmine.

K

Kahn, Bob* (b. December 23, 1938): American. Kahn and Vinton Gray Cerf developed the packet network interconnection protocols (TCP/IP), the system of technical rules used to transfer information though the Internet.

Kalashnikov, Mikhail (b. November 10, 1919): Russian. In 1947, Kalashnikov designed the AK-47, the most famous and widely used assault rifle.

Kallmann, Hartmut (February 5, 1896-June 11, 1978): German. Kallmann invented the scintillation counter, which measures ionizing radiation.

Kamen, Dean* (b. April 5, 1951): American. Kamen introduced his Segway PT (personal transporter), a self-balancing, electric-powered, two-wheeled platform, in 2001.

Kamerlingh Onnes, Heike* (September 21, 1853-February 21, 1926): Dutch. A pioneer in ultra-low-temperature physics, Kamerlingh Onnes liquefied helium and discovered superconductivity, for which he was honored with the 1913 Nobel Prize in Physics.

Kane, Nathan (b. 1968): American. Based on mathematical analysis, Kane built low-distortion bellows of maximum efficiency.

Kapitsa, Pyotr Leonidovich* (July 8, 1894-April 8, 1984): Russian. Kapitsa received the 1978 Nobel Prize in Physics for his investigations into the superfluidity of liquid helium and basic inventions in low-temperature physics.

Kármán, Theodore von (May 11, 1881-May 7, 1963): Hungarian American. An engineer in the early U.S. space program, von Kármán developed the mathematical analysis of fluid dynamics, especially turbulence, and its application to jet aircraft and rockets.

Kay, John* (July 16, 1704-1780 or 1781): English. Kay introduced the flying shuttle in weaving, which sped up the process of making cloth.

Keck, Donald (b. January 2, 1941): American. In 1970, Keck, Robert Maurer, and Peter Schultz produced the first optical fiber, which transmitted 65,000 times more information than copper wire.

Keichline, Anna Wagner (1889-1943): American. Keichline patented the K Brick, a precursor of the cement block, in 1927.

Kellogg, John Harvey* (February 26, 1852-December 14, 1943): American. An advocate of a healthy diet and exercise, Kellogg developed the ready-to-eat breakfast cereal of flaked whole grain.

Kelman, Charles (May 23, 1930-June 1, 2004): American. In 1967, Kelman introduced the phacoemulsification procedure, a form of cataract surgery that greatly shortened the recovery period.

Kelvin, Lord* (June 26, 1824-December 17, 1907): Irish. Lord Kelvin (William Thomson) was a master inventor of measuring devices and metrics, most famously the Kelvin temperature scale, which begins at absolute zero (0 kelvin).

Kemeny, John George (May 31, 1926-December 26, 1992): Hungarian American. With Thomas Kurtz, Kemeny created Beginners All-Purpose Symbolic Instruction Code (BASIC), a computer language first tested in 1964.

Kemurdzhian, Alexander (October 4, 1921-February 25, 2003): Russian. Kemurdzhian designed Lunokhod 1, the first space-exploration rover, which roamed on the Moon in 1970.

Kendall, Edward Calvin (March 8, 1886-May 4, 1972): American. Kendall shared the 1950 Nobel Prize in Physiology or Medicine for his work in isolating and analyzing hormones of the adrenal cortex, especially cortisone.

Kepler, Johannes (December 27, 1571-November 15, 1630): German. Kepler invented modern astronomy with his discovery of the three laws of planetary motion, which prove that the universe does not operate by caprice.

Kerst, Donald William (November 1, 1911-August 19, 1993): American. Kerst designed the betatron (1940), the first particle accelerator based on magnetic induction.

Kettering, Charles F.* (August 29, 1876-November 25, 1958): American. Kettering invented widely, producing, for instance, an improved railroad engine, refrigerators, a torpedo, automobiles, and unmanned aircraft.

Khalid (fl. ninth century): Ethiopian. Khalid is credited with discovering the stimulating effects of coffee, c. 850 C.E., and ground and boiled the beans for consumption.

Khan, Fazlur Rahman (April 3, 1929-March 27, 1982): Indian American. Kahn developed the shear wall frame interaction system, framed-tube structure, and tube-in-tube structure that made modern skyscrapers possible.

Khorana, Har Gobind (b. January 9, 1922): Indian American. Khorana shared the 1968 Nobel Prize in Physiology or Medicine for his work in protein synthesis and in 1970 was the first to synthesize a gene.

Khwārizmī, al-* (c. 780-c. 850): Persian. Al-Khwārizmī was among the scholars who gathered scientific knowledge and mathematics from Indian, Greek, and Roman sources and developed it further. Afterward, this learning passed into Europe.

Kies, Mary Dixon (1752-1837): American. In 1809, Kies became the first woman to be granted a patent in the United States. Her invention was a process to weave straw with silk or thread for the hatmaking industry.

Kilby, Jack St. Clair* (November 8, 1923-June 20, 2005): American. Kilby received the 2000 Nobel Prize in Physics as the inventor of the integrated circuit; he also developed a hand calculator and thermal printer.

Kindī, al- (Alkindus) (c. 801-873): Yemeni. The first philosopher in the Arab tradition to draw from Greek thought, al-Kindī was also the first to describe the distillation of pure alcohol.

King, Mary-Claire* (b. February 27, 1946): American. King established that a genetic mechanism can exist for cancer when she identified the gene responsible for some breast and ovarian cancers.

Kingsbury, Albert (December 23, 1863-July 28, 1943): American. Kingsbury invented the durable tilting-pad thrust bearing in 1912; his bearings could withstand high pressure and increased the performance and life of many machines.

Kirchhoff, Gustav (March 12, 1824-October 17, 1887): German. With Robert Wilhelm Bunsen, Kirchhoff promulgated the theory of spectrum analysis and coinvented the recording spectroscope.

Klatte, Fritz (March 28, 1880-February 11, 1934): German. Klatte patented his process for synthesizing vinyl acetate in 1913, also known as polyvinyl chloride (PVC).

Kleist, Dale (1909-1998): American. In 1932, Kleist developed the steam-blown process for making fiberglass.

Kleist, Ewald Georg von* (June 10, 1700-December 11, 1748): German. Independently of Pieter van Musschenbroek, von Kleist invented the Leiden jar, an early capacitor that stored electricity produced by friction.

Knight, Margaret E.* (February 14, 1838-October 12, 1914): American. A versatile mechanical engineer, Knight is best known for designing a machine that manufactured square-bottom paper grocery bags.

Knunyants, Ivan Ludvigovich (June 4, 1906-December 21, 1990): Armenian Russian. Knunyants invented polycaprolactam (nylon-6) and was a central figure in the Soviet chemical weapons program.

Koch, Robert (December 11, 1843-May 27, 1910): German. A founder of bacteriology and public health, Koch received the 1905 Nobel Prize in Physiology or Medicine for discovering several human pathogens, and he developed a method for culturing bacteria on a solid medium.

Kolff, Willem Johan* (February 14, 1911-February 11, 2009): Dutch American. Kolff designed the first dialysis machine, which cleansed the blood of people with kidney failure.

Kollsman, Paul (February 22, 1900-September 26, 1982): German American. Kollsman made it possible for pilots to fly by instruments with his invention of the barometric altimeter in 1928.

Kompfner, Rudolf (May 16, 1909-December 3, 1977): Austrian American. In 1943, Kompfner invented the traveling wave tube, which amplifies radio signals to high power.

Koontz, Roscoe* (December 16, 1922-May 17, 1997): American. Koontz was a pioneer in creating safety procedures to protect workers from radiation at nuclear reactors, thereby helping to establish the field of health physics.

Kornberg, Arthur (March 3, 1918-October 26, 2007): American. Kornberg isolated the enzyme DNA polymerase, with which he made copies of DNA. He shared the 1959 Nobel Prize in Physiology or Medicine for his work.

Korolyov, Sergey (January 12, 1907-January 14, 1966): Russian. Korolyov led the team that developed the first intercontinental ballistic missile (ICBM) and was chief designer of the rockets in the Soviet space program from 1953 until his death.

Kotelnikov, Gleb (1872-November 22, 1944): Russian. Kotelnikov invented the knapsack parachute, which was first tested in 1912.

Kroll, William (November 24, 1889-March 30, 1973): Luxembourger American. In 1932, Kroll developed a process for mass producing ductile metallic titanium, later a key material in aircraft.

Kulibin, Ivan (April 21, 1735-August 11, 1818): Russian. As well as many optical, acoustic, and measuring instruments, Kulibin invented a searchlight in 1779 and a mechanical elevator in 1794.

Kurchatov, Igor (January 12, 1903-February 7, 1960): Russian. Kurchatov led the Soviet program to develop nuclear weapons, beginning in 1943. He also oversaw construction of a Russian cyclotron (1949) and its first nuclear power plant (1954).

Kurzweil, Ray* (b. February 12, 1948): American. Kurzweil invented several advanced computer-based pattern-recognition (expert systems) technologies for use in finance, music composition and instrumentation, and other fields.

Kwolek, Stephanie* (b. July 31, 1923): American. Kwolek discovered liquid crystalline polymers, which made possible the development of the high-performance fiber Kevlar.

Kyan, John Howard (1774-1850): Irish. Kyanising, which Kyan patented in 1832, was a method of preserving wood by soaking it in mercuric chloride.

L

Laënnec, René-Théophile-Hyacinthe* (February 17, 1781-August 13, 1826): French. Laënnec's invention of the stethoscope in 1816 improved the accuracy of diagnoses for heart and chest problems.

Lakhovsky, Georges (1869-1942): Russian French. Working with Nikola Tesla, Lakhovsky developed the multiple-wave oscillator, used in alternative medicine for electromagnetic therapy.

Lamarr, Hedy (November 9, 1913-January 19, 2000): Austrian American. A leading Hollywood actress, in 1941 Lamarr invented the spread-spectrum radio system with composer George Antheil. It could foil jamming and was intended for a radio-guided torpedo system.

Lambert, John William (January 29, 1860-May 20, 1952): American. In 1890, Lambert constructed a car powered by a single-cylinder gasoline engine. He later patented a friction transmission.

Lanchester, Frederick William (October 23, 1868-March 8, 1946): English. Lanchester built the first automobile in England in 1896 and was a pioneer aeronautics engineer.

Land, Edwin Herbert* (May 7, 1909-March 1, 1991): American. Land introduced instant photography in sepia (1947), black and white (1950), and color (1963).

Langer, Alois A. (b. February 24, 1945): American. Langer engineered the first implantable cardioverter-defibrillator (ICD), which automatically corrects irregular heartbeats to avoid heart failure.

Langer, Robert S. (b. August 29. 1948): American. A leader in biomedical engineering, Langer developed controlled drug delivery in 1986 and pioneered remotely controlled drug delivery and tissue engineering.

Langevin, Paul (January 23, 1872-December 19, 1946): French. Langevin was a central figure in the development of submarine detection by echolocation during World War I, a technology later called sonar.

Langley, Samuel Pierpont* (August 22, 1834-February 27, 1906): American. A pioneer in aviation and an astronomer, Langley was also the inventor of the bolometer, which measures radiant electromagnetic energy.

Langmuir, Irving* (January 31, 1881-August 16, 1959): American. Langmuir developed a successful type of incandescent bulb, and his work in surface chemistry brought him the 1932 Nobel Prize in Chemistry.

Langstroth, Lorenzo Lorraine (December 25, 1810-October 6, 1895): American. Langstroth invented a beehive for domesticated bees in 1851, multiplying honey production.

Lanston, Tolbert (February 3, 1844-February 18, 1913): American. Lanston invented the monotype typesetting machine in 1885, the first to cast individual type and justify the margins line by line.

Latimer, Lewis Howard* (September 4, 1848-December 11, 1928): American. Among Latimer's inventions were a "Water Closet for Railroad Cars," patented in 1874, and improvements in the manufacture of light bulbs.

Lauks, Imants (fl. late twentieth century): Canadian. In 1986, Lauks and Jan Van der Spiegel developed the silicon chip blood analyzer.

Lauterbur, Paul Christian (May 6, 1929-March 27, 2007): American. Lauterbur conceived the nuclear magnetic resonance in magnetic resonance imaging (MRI), for which he shared the 2003 Nobel Prize in Physiology or Medicine.

Laval, Gustaf de (May 9, 1845-February 2, 1913): Swedish. A prolific inventor, de Laval is particularly known for his continuously operating centrifugal cream separator and the de Laval nozzle, a component in steam engines.

Lawes, John Bennet (December 28, 1814-August 31, 1900): English. In 1842, Lawes perfected his process for making the chemical fertilizer superphospate and launched the artificial fertilizer industry.

Lawrence, Ernest Orlando* (August 8, 1901-August 27, 1958): American. Lawrence invented the cyclotron, a circular particle accelerator that made possible the direct investigation of the atomic nucleus and produced new radioactive isotopes.

Lear, Bill* (June 26, 1902-May 14, 1978): American. Lear invented the eight-track tape recorder, an autopilot system for aircraft, and the two-engine commercial Learjet.

Lebedev, Sergei Vasilyevich (July 25, 1874-May 2, 1934): Russian. In 1910, Lebedev produced a synthetic elastic rubber from polybutadiene.

Le Caine, Hugh* (May 27, 1914-July 3, 1977): Canadian. A founder of electronic music, Le Caine introduced the Electronic Sackbut and the Special Purpose Tape Recorder.

Ledley, Robert Steven* (b. June 28, 1926): American. Ledley's automatic computerized transverse axial (ACTA) X-ray scanner, introduced in 1973, first afforded physicians three-dimensional, whole-body images.

Leduc, René (1898-1968): French. In 1949, Leduc built the first aircraft to be powered by ramjet engines, which he patented in 1935.

Leeuwenhoek, Antoni van* (October 24, 1632-August 26, 1723): Dutch. Leeuwenhoek pioneered the design, construction, and use of microscopes. His discovery of microorganisms opened a new world to science.

Leibniz, Gottfried Wilhelm* (July 1, 1646-November 14, 1716): German. As well as coinventing calculus, Leibniz constructed a calculating machine and a binary system of numeration.

Leith, Emmett* (March 12, 1927-December 23, 2005): American. With Juris Upatnieks, Leith displayed the first hologram, a three-dimensional image, in 1964.

Leland, Henry Martin (February 16, 1843-March 26, 1932): American. A founder of Lincoln Motor Company and Cadillac, Leland introduced interchangeable parts in automotive construction and contributed to the V-8 engine and electric starter.

Lemelson, Jerome H.* (July 18, 1923-October 1, 1997): American. Second only to Thomas Alva Edison as America's most prolific inventor, Lemelson innovated such technology as machine vision, automated teller machines (ATMs), and videocassette recorders.

Lenoir, Étienne* (January 12, 1822-August 4, 1900): Belgian French. Lenoir invented a two-stroke internal combustion engine fired by a mixture of coal gas and air; it contained the first spark plug, patented in 1860.

Lenormand, Louis-Sébastien* (1757-1837): French. As well as coining the word "parachute," Lenormand is credited with making the first successful parachute descent.

Leonardo da Vinci* (April 15, 1452-May 2, 1519): Italian. Of the myriad inventions by this great Renaissance painter, the most renowned involved flying. His design for a glider was tested successfully in the twenty-first century.

LeTourneau, Robert Gilmore (November 30, 1888-June 1, 1969): American. With some three hundred patents, LeTourneau introduced many innovations in earthmoving equipment, such as the heavy-duty rubber tire and electric wheel drive.

Libby, Willard F.* (December 17, 1908-September 8, 1980): American. Libby received the 1960 Nobel Prize in Chemistry for inventing radiocarbon dating. It traces the decay of carbon-14 in order to determine the age of materials.

Liebig, Justus von (May 12, 1803-April 18, 1873): German. The founder of agricultural chemistry, Liebig discovered that nitrogen was a basic plant nutrient-based fertilizer and developed the first inorganic fertilizers.

Lilienthal, Otto (May 23, 1848-April 10, 1896): German. In 1891, Lilienthal built the first human-carrying hang glider.

Linde, Carl von* (June 11, 1842-November 16, 1934): German. Linde developed modern refrigeration technology and a technique for extracting pure oxygen and nitrogen from air.

Lindqvist, Frans Wilhelm (1862-1931): Swedish. In 1892, Lindqvist invented the sootless kerosene stove and started a company, Primus, to market it.

Link, Edwin Albert* (July 26, 1904-September 7, 1981): American. Link's invention of the flight simulator allowed pilots to develop flying skills without leaving the ground.

Lippershey, Hans* (c. 1570-September, 1619): Dutch. A maker of eyeglasses, Lippershey also made an early refracting telescope, which many scholars believe was the first.

Lippmann, Gabriel* (August 16, 1845-July 13, 1921): French. Lippmann's color photography process based on the interference phenomenon brought him the 1908 Nobel Prize in Physics.

Littleton, Jesse T. (1888-1966): American. Littleton is credited with recognizing the potential of Nonex, the precursor of Pyrex glass, in cooking vessels and testing it in 1913.

Livens, William Howard (1889-1964): English. Livens invented chemical and incendiary weapons, notably the Livens Projector, which could hurl containers of toxic chemicals.

Livingston, M. Stanley* (May 25, 1905-August 25, 1986): American. Livingston worked with Ernest Orlando Lawrence to build the first cyclotron and later designed other particle accelerators used in nuclear research.

Lodge, Oliver Joseph (June 12, 1851-August 22, 1940): English. Lodge invented the coherer—the radio-wave detector in early radiotelegraph receivers—in 1894.

Lodygin, Alexander (1847-1923): Russian. Lodygin demonstrated his lamp with a carbon-filament incandescent light bulb in 1873.

Long, Crawford Williamson (November 1, 1815-July 16, 1878): American. In 1842, Long used ether as an anesthetic during surgery to remove a neck tumor, the first physician to do so.

Losev, Oleg (1903-1942): Russian. In the early 1920's, Oleg independently discovered the principle of the light-emitting diode.

Lovelace, Ada (December 10, 1815-November 27, 1852): English. Lovelace introduced the basis for computer programming in a 1843 commentary describing how to operate Charles Babbage's difference engine.

Low, Archibald Montgomery (1888-September, 1956): English. Low invented a forerunner of the television and guidance systems for torpedoes, airplanes, and rockets.

Lumière, Auguste and Louis* (October 19, 1862-April 10, 1954 [Auguste]; October 5, 1864-June 6, 1948 [Louis]): French. Auguste and Louis Lumière invented the cinématographe, a motion-picture system, and started the movie theater business.

Lundström, John Edvard (1815-1888): Swedish. In 1855, Lundström invented a safety match that lit when the fire-starting chemicals on its head were scraped across a red phosphorous strip on the matchbox.

Luppis, Giovanni (1813-1875): Austrian. A commander in the Austrian navy, in 1866 Luppis devised a self-propelled, steerable torpedo with Robert Whitehead's help.

Lyons, Harold (February 16, 1913-March 23, 1998): American. Lyons oversaw the construction of the first atomic clock in 1948. It was accurate to one second in 231 days.

M

Ma Jun (c. 200-c. 260): Chinese. Ma Jun developed the compass vehicle, a nonmagnetic mechanical device that served as a directional compass.

McAdam, John Loudon* (September 21, 1756-November 26, 1836): Scottish. McAdam's method of paving road surfaces with three layers of broken stone, called macadam, and lining them with drainage ditches made roads hardier and easier to maintain.

McCormick, Cyrus Hall* (February 15, 1809-May 13, 1884): American. The McCormick reaper, patented in 1834, increased the efficiency and lowered the cost of harvesting, fostering the development of agriculture in the American West.

McCoy, Elijah* (March 27, 1843, or May 2, 1844-October 10, 1929): Canadian American. McCoy concentrated his inventive genius on locomotives, producing more than fifty devices, including an automatic lubricator.

MacCready, Paul B.* (September 29, 1925-August 28, 2007): American. MacCready built the Gossamer Condor, which won the Kremer Prize in 1977 as the first human-powered aircraft.

McIntire, Otis Ray (August 24, 1918-February 2, 1996): American. In 1944, McIntire patented extruded polystyrene foam, better known by its brand name, Styrofoam.

Macintosh, Charles* (December 29, 1766-July 25, 1843): Scottish. In 1823, Macintosh patented the first raincoat, waterproofed by sandwiching soluble rubber between layers of cloth.

McLean, Malcolm Purcell (November 14, 1914-May 25, 2001): American. McLean founded Sea-Land and started the first containerized shipping system in 1956, transforming the trucking industry.

McMaster, Harold (July 20, 1916-August 25, 2003): American. McMaster invented tempered glass by pressing glass to increase tensile strength.

MacMillan, Kirpatrick (1812-January 26, 1878): Scottish. In 1839 MacMillan invented the first bicycle to be propelled by pedaling.

MacPherson, Cluny (1879-1966): Canadian. MacPherson devised the MacPherson respirator, a type of gas mask, in 1915, the first generally used protection from chemical weapons.

Madhani, Akhil J. (b. 1968): Kenyan American. Madhani produced the Black Falcon telerobotic surgical system in 1997, designed to improve the surgeon's control and minimize trauma to the patient.

Maiman, Theodore Harold* (July 11, 1927-May 5, 2007): American. Maiman designed and built the first operable laser, using a synthetic ruby as the amplifier, and he foresaw many applications for the laser.

Maksutov, Dmitri Dmitrievich (1896-1964): Russian. The Maksutov telescope, invented in 1941, uses a corrector plate to eliminate spherical aberrations that distort images.

Manby, George William (November 28, 1765-November 18, 1854): English. Manby invented the first fire extinguisher, patented in 1813. It involved a nozzled copper cylinder with water and compressed air.

Mannes, Leopold* (December 26, 1899-August 11, 1964): American. Mannes worked out the process to produce Kodachrome color film with fellow musician Leopold Godowsky, Jr.

Mansfield, Peter (b. October 9, 1933): English. Mansfield shared the 2003 Nobel Prize in Physiology or Medicine for providing the mathematical analysis necessary to produce images in magnetic resonance imaging (MRI).

Marconi, Guglielmo* (April 25, 1874-July 20, 1937): Italian. Marconi shared the 1909 Nobel Prize in Physics for his improvements in wireless telegraphy and his long-distance wireless transmission across the Atlantic Ocean.

Marrison, Warren Alvin (May 21, 1896-March 27, 1980): Canadian American. With J. W. Horton, in 1927 Marrison built the first clock that monitored time with a quartz oscillator.

Mars, Forrest (March 21, 1904-July 1, 1999): American. The heir to Mars, Inc., the family candy company, Mars invented the Mars Bar in 1932 and M&M's in 1940.

Mason, John Landis (1832-February 26, 1902): American. In 1858, Mason patented a square-shouldered glass jar for preserving food. The Mason jar produced a seal with a zinc screw cap.

Mason, Stanley (August 18, 1921-December 6, 2006): American. Mason invented a wide variety of common goods, such as the squeezable ketchup bottle, the baby-shaped disposable diaper, the granola bar, and microwave cookware.

Massie, Thomas (b. 1971): American. In 1993, with Kenneth Salisbury, Massie invented the Phantom haptic interface, a device that helps computer users "feel" images of three-dimensional objects on the computer screen, part of a virtual reality system.

Matzeliger, Jan Ernst* (September 15, 1852-August 24, 1889): American. American shoe manufacturing increased dramatically following the introduction of Matzeliger's shoe-lasting machine, patented in 1883.

Mauchly, John William* (August 30, 1907-January 8, 1980): American. Mauchly worked with John Presper Eckert in designing and building ENIAC, the first general-purpose electronic digital computer.

Maudslay, Henry (August 22, 1771-February 14, 1831): English. Maudslay introduced the metal lathe and bench micrometer, both crucial to manufacturing in the Industrial Revolution.

Maxim, Hiram Percy* (September 2, 1869-February 17, 1936): American. More than his various automotive inventions, Maxim is known for creating the firearm silencer, patented in 1909.

Maxim, Hiram Stevens* (February 5, 1840-November 24, 1916): American. The Maxim gun, patented in 1885, was the first recoil-driven machine gun.

Maxim, Hudson* (February 3, 1853-May 6, 1927): American. A chemist, Maxim produced a smokeless gunpowder and maximite (mono-nitro-naphthalene), which is 50 percent more powerful than dynamite.

Maxwell, James Clerk (June 13, 1831-November 5, 1879): Scottish. Maxwell's electromagnetic theory and attendant equations (published 1873) constituted a fundamental advance in physics.

Maybach, Wilhelm (February 9, 1846-December 29, 1929): German. Maybach led the team that designed the Mercedes automobile in 1901.

Maynard, Edward (1813-1891): American. In 1845, Maynard patented a percussion-cap primer for rifles and in 1851 a lightweight breech-loading rifle that used a metallic cartridge of his design.

Mazor, Stanley (b. October 22, 1941): American. With Ted Hoff and Federico Faggin, Mazor helped design the first microprocessor chip in 1971.

Mead, Carver Andress (b. May 1, 1934): American. A pioneer in computer chip design, Mead configured the first gallium-arsenide metal epitaxial semiconductor field effect transistor (MESFET), used in modern wireless electronics.

Mège-Mouriés, Hippolyte (October 24, 1817-May 31, 1880): French. In 1869, Mège-Mouriés patented his process for producing margarine from animal fat and skim milk, which won a government award as a substitute for butter.

Meikle, Andrew (1719-November 27, 1811): Scottish. In 1788, Meikle patented a threshing machine that removed the outer husks from grains of wheat.

Mendeleyev, Dimitry Ivanovich* (February 8, 1834-February 2, 1907): Russian. Mendeleyev's periodic table of elements is among the greatest achievements of modern chemistry.

Mercator, Gerardus* (March 5, 1518-December 2, 1594): Flemish. Widely considered to be the first modern cartographer, Mercator created a method for projecting a map of the globe onto a flat surface.

Mergenthaler, Ottmar* (May 11, 1854-October 28, 1899): German American. Mergenthaler's key-operated typesetting machine, the Linotype (introduced in 1884), multiplied the speed and accuracy of printing.

Merryman, Jerry D. (b. 1932): American. With Jack St. Clair Kilby and James H. Van Tassel, Merryman invented the handheld electronic calculator in 1967.

Mestral, Georges de* (June 19, 1907-February 8, 1990): Swiss. In 1955, Mestral patented Velcro, the hook-and-loop fastener. The idea came to him while examining how the hooked barbs of burrs stuck to his clothing.

Metcalfe, Robert* (b. April 7, 1946): American. With David Boggs, Metcalfe coinvented the Ethernet, a system linking computer terminals in a local network.

Meucci, Antonio (April 13, 1808-October 18, 1889): Italian. Meucci built a prototype telephone sometime after conceiving the underlying principle in 1849.

Michelin, André and Édouard* (January 16, 1853-April 4, 1931 [André]; June 23, 1859-August 25, 1940 [Édouard]): French. The Michelin brothers ran Michelin Tire Company, incorporated in 1888, a pioneer manufacturer of pneumatic tires.

Midgley, Thomas, Jr. (May 18, 1889-November 2, 1944): American. Midgley discovered in 1921 that adding tetraethyl lead to gasoline eliminated preignition "knocking."

Miles, Alexander (1838-unknown): American. In 1887, Miles patented his automatically shutting and opening elevator doors, an improvement in safety.

Miller, Lewis (July 24, 1829-February 17, 1899): American. A founder of the Chautauqua Institution for popular education, Miller also invented the combine harvester with the blade mounted in front of the driver.

Miller, Stanley Lloyd (March 7, 1930-May 20, 2007): American. With Harold Urey, Miller designed an experiment that synthesized amino acids from a mixture of gases thought to mimic Earth's early atmosphere—theoretically, a step in the generation of life.

Millman, Irving (b. May 23, 1923): American. In 1963, Millman and Baruch S. Blumberg developed a test to detect the hepatitis B virus in blood samples and then created a vaccine to protect people from it.

Milne, John* (December 30, 1850-July 31, 1913): English. Milne devised a seismograph and established the first international seismological network for detecting and measuring earthquakes.

Mirowski, Michel (October 14, 1924-March 26, 1990): Polish American. Mirowsky oversaw development of the automatic implantable cardioverter-defibrillator (ICD), which corrects potentially fatal irregular heartbeats.

Moeller, Dennis (b. 1950): American. While working for International Business Machines (IBM), Moeller helped design the Industry Standard Architecture (ISA) computer architecture, introduced in 1984, that connects peripheral devices to personal computers.

Molchanov, Pavel (1893-1941): Russian. A meteorologist, Molchanov built and in 1930 launched the radiosonde, a package of atmospheric instruments and a radio transmitter attached to a balloon.

Molloy, Bryan B. (March 30, 1939-May 8, 2004): Scottish American. Molloy and Klaus Schmiegel developed the active agent in the widely used antidepressant Prozac, introduced in 1988.

Monier, Joseph* (November 8, 1823-March 13, 1906): French. Monier's invention of concrete reinforced with iron mesh, patented in 1867, became a standard material in the construction of buildings and bridges.

Montagnier, Luc (b. August 18, 1932): French. A leading virus researcher, Montagnier discovered the human immunodeficiency virus (HIV) virus in 1983 with Françoise Barré-Sinoussi and Jean-Claude Chermann, and HIV-2 in 1986.

Montgolfier, Joseph-Michel and Jacques-Étienne* (August 26, 1740-June 26, 1810 [Joseph-Michel]; January 6, 1745-August 2, 1799 [Jacques-Étienne]): French. The Montgolfier brothers built the first hot-air balloon, launched in 1782.

Montgomery, John J. (February 15, 1858-October 31, 1911): American. Montgomery built the first successful American monoplane glider in 1884 and may have discovered how air circulation past the wings provides lift.

Monturiol i Estarriol, Narcís (September 28, 1819-September 6, 1885): Spanish. In 1862, Monturiol i Estarriol built the first steam-powered submarine.

Moog, Robert* (May 23, 1934-August 21, 2005): American. The keyboard-played Moog synthesizer, first demonstrated in 1964, introduced a new range of sound to popular music.

Moore, Hugh (April 27, 1887-November 25, 1972): American. With his brother-in-law, Lawrence Luellen, Moore invented disposal drinking cups, first called Health Kups and later Dixie Cups.

Morey, Samuel (October 23, 1762-April 17, 1843): American. Morey received several patents on improvements to steam engines and in 1826 a patent on a two-cylinder internal combustion engine that ran on turpentine.

Morgan, Garrett Augustus* (March 4, 1877-July 27, 1963): American. Morgan invented the safety hood, a precursor to the gas mask, and the three-armed traffic signal, which later morphed into the three-color traffic light.

Morlan, Krysta (b. 1983): American. When she was a tenth grader, Morlan invented the cast cooler, a battery-powered device that relieves irritation for those wearing casts by funneling in cool air.

Morse, Samuel F. B.* (April 27, 1791-April 2, 1872): American. Initially a portrait painter, Morse invented the code of dots and dashes for telegraphy and, in 1844, sent the first long-distance message over his own telegraph system.

Mower, Morton (b. January 31, 1933): American. Mower coinvented the automatic implantable cardioverter-defibrillator (ICD) with Stephen Heilman, Alois A. Langer, and Michel Mirowsky. The first was implanted in 1980.

Müller, Erwin Wilhelm* (June 13, 1911-May 17, 1977): German American. Müller invented the field-emission microscope, field-ion microscope, and atom-probe microscope.

Müller, Karl Alexander* (b. April 20, 1927): Swiss. With J. Georg Bednorz, Müller discovered high-temperature superconductivity in novel ceramic materials, receiving the 1987 Nobel Prize in Physics for their work.

Müller, Paul (January 12, 1889-October 12, 1965): Swiss. Müller discovered that dichlorodiphenyltrichloroethane (DDT) was a powerful insecticide, for which he received the 1948 Nobel Prize in Physiology or Medicine.

Mullis, Kary B.* (b. December 28, 1944): American. Mullis's invention of the polymerase chain reaction (PCR) in 1983 made it possible to replicate deoxyribonucleic acid (DNA) rapidly in order to study genetic variation, with applications in medicine and forensic science.

Murdock, William* (August 21, 1754-November 15, 1839): Scottish. Murdock pioneered the use of coal gas for commercial and domestic lighting.

Murgaš, Jozef (February 17, 1864-May 11 or 23, 1929): Slovak. A Catholic priest, Murgaš built an early radiotelegraph station and put on public demonstrations in 1905.

Murphy, William, Jr. (b. November 11, 1923): American. Murphy invented the disposable medical tray in 1961, which reduced bacterial contamination in surgeries.

Musschenbroek, Pieter van* (March 14, 1692-September 19, 1761): Dutch. Musschenbroek is credited with the invention of the Leiden jar in 1746, a precursor of the capacitor that stored static electricity.

N

Naismith, James (November 6, 1861-November 28, 1939): Canadian American. Naismith invented basketball in 1891 and may have introduced the football helmet as well.

Naito, Ryoichi (1906-July, 1982): Japanese. Naito developed Fluosol-DA, an artificial blood that keeps tissue healthy during surgical procedures, first tested in 1978.

Nakamatsu, Yoshiro (b. 1928): Japanese. Holder of thousands of patents, Nakamatsu developed technology behind the floppy disk, compact disc (CD), digital video disc (DVD), digital watch, and taxicab meter.

Nakamura, Shuji* (b. May 22, 1954): Japanese American. Nakamura's invention of the blue light-emitting diode and blue laser diode fostered advances in energy-efficient lighting and optical data storage.

Nakao, Naomi L.* (b. January 13, 1948): Israeli American. Nakao made several important improvements to the equipment used in gastroenterological procedures, including an endoscopic/laparoscopic stapler, the Nakao Snare line, and the Nakao EndoRetractor.

Napier, John* (1550-April 4, 1617): Scottish. Napier greatly simplified calculations necessary in navigation and astronomy with his development of logarithmic tables.

Nasmyth, James* (August 19, 1808-May 7, 1890): Scottish. Nasmyth's steam hammer became a significant tool in the early Industrial Revolution, capable of a wide range of jobs in metalworking.

Natta, Giulio (February 26, 1903-May 2, 1979): Italian. Natta shared the 1963 Nobel Prize in Chemistry for research on high polymers, including production of polypropylene.

Nestlé, Henri* (August 10, 1814-July 7, 1890): German Swiss. Nestlé produced many innovative foods and beverages, most notably an infant formula for bottle-fed babies. He hoped that it would reduce the mortality rate.

Neumann, Gerhard (October 8, 1917-November 2, 1997): German American. Neumann developed the variable-stator jet engine in 1952, which was the first to power an aircraft past Mach 2.

Neustadter, Alfred (1911-1996): American. In 1950, Neustadter marketed the Rolodex, a rotary filing system for note cards, which his employee Hildaur Neilsen had invented and later patented.

Newcomen, Thomas* (January or February, 1663-August 5, 1729): English. Newcomen's steam engine, the first to do practical work reliably, made possible the age of industry.

Newton, Sir Isaac* (December 25, 1642-March 20, 1727): English. Newton's contributions to science were varied and profound, among them the nature of optics, celestial mechanics, and the calculus, arrived at independently of Gottfried Wilhelm Leibniz.

Niépce, Nicéphore* (March 7, 1765-July 5, 1833): French. Niépce made the first lasting photographic images, which he called "heliography" (sun drawing), in 1818, after some twenty years of experimentation.

Nieuwland, Julius (February 14, 1878-June 11, 1936): Belgian American. Nieuwland invented the first synthetic rubber, neoprene, marketed in 1932.

Nipkow, Paul (August 22, 1860-August 24, 1940): German. Nipkow patented a mechanical, rotating disk television system in 1884, thought to be the first such system.

Nishizawa, Jun-ichi (b. September 12, 1926): Japanese. Known as the "father of Japanese microelectronics," Nishizawa developed fundamental semiconductor materials, the pin diode, and the static induction transistor.

Nobel, Alfred* (October 21, 1833-December 10, 1896): Swedish. Nobel's invention of dynamite was important to heavy construction and warfare. The international prizes given in his name for chemistry, economics, medicine, physics, literature, and peace became the modern emblems of genius.

Nobile, Arthur (May 6, 1920-January 13, 2004): American. Nobile invented the steroids prednisone and prednisolone in 1950, which became widely used anti-inflammatory drugs.

Northrop, John Howard (July 5, 1891-May 27, 1987): American. Northrop received the 1946 Nobel Prize in Chemistry for his research on enzymes, proteins, and viruses. He also invented a fermentation process for acetone.

Noyce, Robert Norton* (December 12, 1927-June 30, 1990): American. The digital revolution of mass-produced computer circuitry proceeded from Noyce's development of the integrated circuit.

Nyberg, Carl Richard (May 28, 1858-1939): Swedish. Nyberg invented the blowtorch and began manufacturing it in 1882.

O

Ochoa, Ellen (b. May 10, 1958): American. The first Hispanic female astronaut, Ochoa patented an optical inspection system, an optical recognition system, and a method for noise removal in images.

Ochoa, Severo (September 24, 1905-November 1, 1993): Spanish American. Ochoa shared the 1959 Nobel Prize in Physiology or Medicine for being the first to assemble synthetic ribonucleic acid (RNA).

Ochoa, Victor Leaton* (1850-c. 1945): Mexican American. The Ochoaplane was an airplane with collapsible wings. Ochoa also invented an adjustable wrench, windmill, and streetcar brake.

Odhner, Theophil Wilgodt (1845-1905): Swedish. The Odhner arithmometer, first built in 1874, was a mechanical adding machine.

Ohain, Hans Joachim Pabst von* (December 14, 1911-March 13, 1998): German American. Von Ohain developed the first working self-contained jet engine, and his engines were the first to power an all-jet aircraft, the Heinkel 178, in 1939.

Olds, Ransom Eli* (June 3, 1864-August 26, 1950): American. As well as building early steam- and gasoline-powered vehicles, Olds innovated the automobile production process.

Oliver, Bernard M. (May 27, 1916-November 23, 1995): American. Oliver invented pulse-code modulation, which enables information to be transmitted in binary code.

Olsen, Ken* (b. February 20, 1926): American. Under Olsen's leadership, Digital Equipment Corporation (DEC) made small computers affordable to businesses, beginning in 1960 with the PDP-1 Minicomputer.

Ondetti, Miguel Angel (May 14, 1930-August 23, 2004): Argentine American. Ondetti invented captopril in 1974, a type of angiotensin-converting enzyme (ACE) inhibitor, which reduces hypertension effectively without burdensome side effects.

Oppenheimer, J. Robert* (April 22, 1904-February 18, 1967): American. A particle physicist and astrophysicist, Oppenheimer led the top-secret Manhattan Project, which detonated the first atomic bomb in 1945.

O'Rear, Dennis (b. November 21, 1950): American. A chemical engineer, O'Rear holds some seventy patents, many involving oil-processing techniques, such as processes to produce lubricating oils.

O'Reilly, Samuel (d. 1908): English American. O'Reilly is the inventor of the electric tattoo machine, patented in 1891.

Ørsted, Hans Christian (August 14, 1777-March 9, 1851): Danish. Ørsted discovered that a magnetized needle is deflected in the presence of an electric current—that is, electromagnetism. He was also the first to produce metallic aluminum.

Otis, Elisha Graves* (August 3, 1811-April 8, 1861): American. Otis invented the first elevator with a safety brake in 1852 and soon after founded the Otis Elevator Company, the leading manufacturer and installer.

Ott, John Nash (October 23, 1909-April 6, 2000): American. Ott pioneered time-lapse photography and discovered health benefits from full-spectrum lighting.

Otto, Nikolaus August* (June 10, 1832-January 26, 1891): German. Otto's four-stroke engine, patented in 1876, marked an important milestone for the development of the internal combustion engine.

Oughtred, William (March 5, 1575-June 20, 1660): English. Oughtred introduced the symbol × for use in multiplication and invented the linear slide rule, which he described in 1621, and probably the circular version as well.

Ovshinsky, Stanford* (b. November 24, 1922): American. Ovshinsky pioneered ovonics, the study of disordered materials, and developed the ovonic switch in 1957, which rendered amorphous materials suitable to a variety of technologies.

Owens, Michael Joseph (January 1, 1859-December 27, 1923): American. Owens's automatic bottle-blowing machine, patented in 1895, could produce four completed bottles per second, reducing labor costs and increasing production for the industry.

P

Page, Charles G. (January 25, 1812-May 5, 1868): American. In 1836, Page invented the high-voltage induction coil, precursor of the modern transformer.

Page, Larry* (b. March 26, 1973): American. Page's development of the PageRank algorithm improved the accuracy with which Internet search engines evaluate the content of a given page on the World Wide Web.

Paige, James W. (1842-1917): American. Paige invented a typesetting machine whose chief virtue was that it attracted the financial support of Mark Twain.

Painter, William (November 20, 1838-July 15, 1906): American. In 1892, Painter created the crown bottle cap, a great improvement for sealing bottles containing a carbonated fluid.

Pall, David Boris (April 2, 1914-September 21, 2004): American. An innovator in filtration systems, Pall invented filters that remove oil impurities from engines and hydraulics and a filter that reduces the number of white blood cells in blood transfusion.

Palmaz, Julio C. (b. 1945): Argentine American. A physician, in 1988 Palmaz patented the first commercially successful intravascular stent, used to open clogged blood vessels.

Palmcrantz, Helge (July 7, 1842-November 22, 1880): Swedish. Palmcrantz invented the multibarrel, lever-actuated machine gun, patented in 1873 and marketed as the Nordenfelt machine gun.

Palmer, Daniel David (March 7, 1845-October 20, 1913): Canadian American. Palmer invented chiropractic, beginning his practice in 1895.

Palmieri, Luigi (April 22, 1807-September 9, 1896): Italian. Palmieri invented a mercury seismometer in 1855 that detected and measured ground movement with great sensitivity. With it, he was able to predict volcanic eruptions.

Papanicolaou, George N. (May 13, 1883-February 19, 1962): Greek American. Papanicolaou developed the pap smear, patented in 1928, a diagnostic test for uterine cancer in women.

Parker, Louis W. (January 1, 1906-June 21, 1993): Hungarian American. Parker invented the intercarrier sound system, patented in 1948, that coordinates sound and images on television and the vertical-line color television system.

Parkes, Alexander (December 29, 1813-June 29, 1890): English. Parkes invented Parkesine, a form of cellulose nitrate, in 1862; it was an early artificial plastic.

Parkhouse, Albert J. (1879-1927): Canadian. Parkhouse invented the coat hanger in 1903.

Parkinson, Bradford (b. 1935): American. Under Parkinson's supervision, the first test version of the Global Positioning System (GPS) was produced by the U.S. Air Force in 1978.

Parsons, Charles* (June 13, 1854-February 11, 1931): English. Parsons built the *Turbinia* and powered it with his invention, the steam turbine. In 1897, it was the world's fastest ship.

Parsons, John T. (October 11, 1913-April 18, 2007): American. An innovator in machining and tooling, Parsons introduced computers to design work and manufacturing and in 1948 developed the numerical control of machines with binary punch cards.

Pascal, Blaise* (June 19, 1623-August 19, 1662): French. Pascal's investigations in physics improved knowledge of hydraulics and led to the invention of the hydraulic press and the syringe.

Pasch, Gustaf Erik (1788-1862): Swedish. A professor of chemistry, Pasch invented a safety match, patented in 1844, which proved too expensive to manufacture for profit.

Pasteur, Louis* (December 27, 1822-September 28, 1895): French. Pasteur's work in microbiology established the germ theory of disease, which afforded new medical treatments, such as vaccines, and he made dairy products safer through his pasteurization process.

Patrick, Ruth* (b. November 26, 1907): American. A pioneer in freshwater biology, Patrick developed tests for assessing the pollution levels in lakes and rivers.

Paul, Les* (June 9, 1915-August 13, 2009): American. Paul provided many of the tools for modern popular music with his invention of the solid-body electric guitar and development of novel recording techniques.

Paulescu, Nicolae (1869-1931): Romanian. Paulescu isolated the hormone insulin and discovered its relation to diabetes, publishing his findings in 1921.

Pearson, Gerald* (March 31, 1905-October 25, 1987): American. Pearson coinvented the silicon photovoltaic (solar) cell at Bell Telephone Laboratories in 1954.

Pelton, Lester (September 5, 1829-March 14, 1918): American. Patented in 1889, the Pelton water turbine involved a rotor driven by a water jet and was important to the commercial development of hydroelectric power.

Pemberton, John Stith* (July 8, 1831-August 16, 1888): American. First marketed as a pain reliever, Colonel Pemberton's invention, Coca-Cola (patented in 1887), was more successful as a thirst-quencher.

Penkala, Slavoljub Eduard (April 20, 1871-February 5, 1922): Croatian. In 1906, Penkala patented his "automatic pencil," the first mechanical pencil.

Perkin, William Henry (March 12, 1838-July 14, 1907): English. Perkin produced the first synthetic dye, patented in 1856. It was aniline purple, better known as mauve.

Perky, Henry (December 7, 1843-June 29, 1906): American. In 1895, Perky received a patent for a machine to produce his invention, shredded wheat.

Perry, Stephen (fl. mid-nineteenth century): English. Perry patented the rubber band in 1845.

Petroff, Peter (October 21, 1919-February 27, 2003): Bulgarian American. Petroff invented the digital wristwatch, first marketed in 1971.

Pfleumer, Fritz (March 20, 1881-August 29, 1945): German. In 1928, Pfleumer patented magnetic tape for sound recording, developed with Heinz Thiele and Wilhelm Gaus.

Piccard, Auguste (January 28, 1884-March 24, 1962): Swiss. Piccard built the first bathyscaphe in 1948, a submersible for deep sea exploration.

Pickering, Thomas R. (1831-February 21, 1895): English American. In 1868, Pickering produced an improved velocipede, a precursor to the bicycle.

Pierce, John R.* (March 27, 1910-April 2, 2002): American. In addition to inventions in the electronics of particle accelerators, Pierce designed the Echo (launched 1960) and Telstar (launched 1962) communication satellites.

Pincus, Gregory (April 9, 1903-August 22, 1967): American. Pincus invented an oral contraceptive; the Pill, as it became known, was approved for use in 1960.

Pitney, Arthur (1871-1933): American. A wallpaper store clerk, in 1902 Pitney patented the postage meter that franked envelopes mechanically.

Plateau, Joseph Antoine Ferdinand (October 14, 1801-September 15, 1883): Belgian. Plateau and his sons invented the phenakistoscope, otherwise known as the stroboscope, in 1832.

Platen, Baltzar von (1898-1984): Swedish. Von Platen and Carl Munters invented gas absorption refrigeration in 1922.

Plimpton, James Leonard (April 14, 1828-1911): American. In 1863, Plimpton patented the "rocker skate," a skate with two axles of two wheels and tilt steering.

Plunkett, Roy J.* (June 26, 1910-May 12, 1994): American. Plunkett synthesized Teflon, patented in 1941. Its nonstick, nonreactive properties transformed the plastics industry.

Poenaru, Petrache (1799-1875): Romanian. In 1827, Poenaru patented a fountain pen and later designed the national flag of Romania.

Polhem, Christopher (December 18, 1661-August 30, 1751): Swedish. A mining engineer, Polhem built an automated factory powered by a water wheel in 1699 and later invented a padlock and inside-mounted door lock.

Polzunov, Ivan (1728-1766): Russian. Polzunov built the first two-cylinder steam engine in 1766 in order to power air pumps in a steel factory.

Poplawski, Stephen (August 14, 1885-December 9, 1956): Polish American. In 1922, Poplawski filed the first of several patents for electric blenders, including one intended for home use in 1940.

Popov, Aleksandr Stepanovich (March 16, 1859-January 13, 1906): Russian. Popov has a claim as the inventor of radio, since he demonstrated radio reception with a coherer in 1895. He also used his device as a lightning detector.

Potts, William L. (1883-1947?): American. A police officer, Potts introduced the three-color traffic light in 1920.

Poulsen, Valdemar (November 23, 1869-July 23, 1942): Danish. In 1898, Poulsen filed a patent for his telegraphone, an all-electric machine that could record thirty minutes of sound on a magnetized wire.

Priestley, Joseph* (March 13, 1733-February 6, 1804): English. A master chemist, Priestley devised lab equipment, discovered oxygen, and invented soda water and an eraser.

Ptolemy* (c. 100-c. 178 C.E.): Egyptian. Ptolemy defined the universe for more than a millennium with his Earth-centered cosmology, but he also wrote about geography and optics.

Pullman, George Mortimer* (March 3, 1831-October 19, 1897): American. After founding the Pullman Palace Car Company in 1867, Pullman brought luxury to train passengers with his plush designs for sleeping, dining, and parlor cars.

Pupin, Michael I. (October 4, 1858-March 12, 1935): Serbian American. In 1893, Pupin invented the resonator, which was subsequently used to tune radios, and in 1894 the Pupin coil, which facilitated long-distance telephone calling.

Pusey, Joshua (1842-1906): American. Pusey invented the paper matchbook in 1889.

Puskás, Tivadar (September 17, 1844-March 16, 1893): Hungarian. With Thomas Alva Edison's help, Puskás invented the telephone exchange in 1877 and ten years later introduced the multiplex switchboard.

Q

Quackenbush, Henry M. (April 27, 1847-September 8, 1933): American. Credited with developing the air rifle, Quackenbush was also the first to patent a nutcracker (1909).

R

Rabinow, Jacob* (January 8, 1910-September 11, 1999): Russian American. Rabinow invented prolifically, producing, for instance, automatic regulating clocks, letter-sorting machines, magnetic computer disk files, and bomb safety mechanisms.

Ramsden, Jesse* (October 6, 1735-November 5, 1800): English. Ramsden's innovations in calibrating measurement instruments enabled him to construct large optical instruments, such as astronomical telescopes.

Reard, Louis (1898-1984): French. Reard invented the bikini in 1946; the name was inspired by the nuclear bomb test at Bikini Atoll in the South Pacific.

Reichenbach, Karl von (1788-1869): German. Von Reichenbach produced several commercially valuable substances from coal and wood tar, including creosote, paraffin, and phenol.

Remsen, Ira* (February 10, 1846-March 4, 1927): American. With Constantin Fahlberg, Remsen synthesized the artificial sweetener saccharin in 1879.

Renault, Louis (February 15, 1877-October 24, 1944): French. Renault invented the direct-drive gearbox for his two-seater car in 1898; it had three speeds and reverse.

Reno, Jesse W.* (August 4, 1861-June 2, 1947): American. Reno patented his moving stairs (or escalator) in 1892. At first a curiosity in the Coney Island amusement park near New York City, the escalator eventually became a fixture in stores throughout the United States and Europe.

Ressel, Josef (June 29, 1793-October 9, 1857): Czech. Ressel developed the first practical ship propeller in 1829.

Richardson, Ken (b. November 26, 1939): English. Richardson led the team that discovered fluconazole in 1981, an antifungal medication that can be given to people with weak immune systems.

Richter, Charles Francis* (April 26, 1900-September 30, 1985): American. A pioneering seismologist, Richter invented the scale for measuring the intensity of earthquakes.

Rickover, Hyman George (January 27, 1900-July 8, 1986): Polish American. Considered the father of the U.S. nuclear submarine service, Rickover oversaw construction of its first vessel, the USS *Nautilus*, launched in 1954.

Rillieux, Norbert* (March 17, 1806-October 8, 1894): American. Rillieux's invention, the vacuum evaporator (patented 1843), allowed sugar refineries to produce sugar more efficiently and with less labor.

Rines, Robert H. (b. August 30, 1922): American. Rines's technical innovations made possible high-resolution image-scanning radar, used in military weapons systems and by explorers seeking sunken ships, such as the *Titanic*.

Rittenhouse, David R. (April 8, 1732-June 26, 1796): American. A celebrated astronomer, Rittenhouse also was an inventor, producing an accurate orrery about 1767 and improving Benjamin Franklin's stove in 1790 by adding an L-shaped chimney.

Ritty, James (1837-1918): American. In 1879, Ritty patented "Ritty's Incorruptible Cashier," the first cash register.

Rochow, Eugene G. (October 4, 1909-March 21, 2002): American. Rochow developed a method to produce silicone polymers in 1940.

Roebling, John Augustus* (June 12, 1806-July 22, 1869): German American. The designer of the Brooklyn Bridge in New York City, Roebling made such suspension bridges possible with his invention of the stranded wire cable in 1841.

Roebuck, John (1718-July 17, 1794): English. In 1746, Roebuck improved the processing of sulfuric acid by replacing glass jars with "lead cathedrals" (condensing chambers).

Rogers, John Raphael (December 11, 1856-February 18, 1934): American. Rogers invented a device that automatically justified type as each line was set for printing.

Rohrer, Heinrich* (b. June 6, 1933): Swiss. The scanning tunneling microscope, which Rohrer developed with Gerd Binnig, gives scientists three-dimensional images of objects as small as a single atom.

Röntgen, Wilhelm Conrad* (March 27, 1845-February 10, 1923): German. Röntgen discovered X rays in 1895 and then put them to use in making images of structures inside the human body, fostering a revolution in medical diagnosis. These achievements brought him the first Nobel Prize in Physics (1901).

Roper, Sylvester* (November 24, 1823-June 1, 1896): American. Roper invented a wide variety of mechanisms but particularly is known for his steam-powered bicycle (1867), the precursor of the gasoline-engine motorcycle.

Rosen, Harold (b. March 20, 1926): American. With patents in skiing, diving, and windsurfing, Rosen is best known for introducing the spin-stabilized satellite in 1957 and directed the team that built the first synchronous (geostationary) communication satellite, in service in 1963.

Rubin, Benjamin A. (b. September 27, 1917): American. Rubin patented his “Pronged Vaccinating and Testing Needle” in 1965. Its forked design makes inoculation against smallpox much faster.

Ruska, Ernst* (December 25, 1906-May 30, 1988): German. Ruska received the 1986 Nobel Prize in Physics for his investigations into electron optics and in particular his design for the electron microscope in 1933.

Russell, James* (b. February 23, 1931): American. Russell invented optical digital recording, patented in 1970, which led to the development of the digital compact disc.

Rutan, Burt* (b. June 17, 1943): American. Rutan designed and built the first private suborbital rocket plane, *SpaceShipOne*. It flew successfully in 2004 in preparation for tourism flights.

S

Sabin, Albert (August 26, 1906-March 3, 1993): Polish American. Sabin developed several vaccines, most famously the oral polio vaccine. Approved for use in 1960, it helped stem an epidemic of polio.

Sakharov, Andrei (May 21, 1921-December 14, 1989): Russian. As well as a Nobel Peace Prize (1975) laureate, Sakharov was a central figure in the Soviet program that developed the hydrogen bomb and conceived of the tokamak nuclear fusion reactor in 1950.

Salk, Jonas* (October 28, 1914-June 23, 1995): American. The Salk vaccine was the first safe, effective killed-virus polio vaccine and contributed to the near elimination of the disease in the United States and many other countries.

Sampson, Henry Thomas* (b. April 22, 1934): American. Sampson’s innovations for aerospace, the military, and industry include methods for preparing rocket propellants and a generator that produces electricity from nuclear radiation.

Samuelson, Ralph (July 3, 1904-August 1977): American. Samuelson is credited with inventing water skiing during the summer of 1922.

Santorio, Santorio* (March 26 or 29, 1561-February 22 or March 6, 1636): Italian. A pioneering physician who studied factors affecting metabolism, Santorio invented a clinical thermometer and other instruments.

Santos-Dumont, Alberto (July 20, 1873-July 23, 1932): Brazilian. In 1898, Santos-Dumont was the first person to build and fly a balloon propelled by a gasoline engine.

Sarett, Lewis Hastings (December 22, 1917-November 28, 1999): American. In 1944, Sarett synthesized the steroid cortisone, a powerful anti-inflammatory agent.

Savery, Thomas* (c. 1650-May, 1715): English. Savery built an early steam engine intended to power drainage pipes, especially for use in mines.

Sax, Adolphe (November 6, 1814-February 4, 1894): Belgian. Sax invented the saxophone in 1841 but also introduced valved bugles and an early version of the contrabass clarinet.

Saxton, Joseph (March 22, 1799-October 26, 1873): American. A versatile inventor, Saxton is best known for producing balances and weights used at the United States Mint in Philadelphia and for measuring instruments, such as a reflecting pyrometer (for measuring the thermal expansion of metal).

Schauberger, Viktor (June 30, 1885-September 25, 1958): Austrian. A naturalist and hydrologist, Schauberger invented efficient flumes for conveying logs, silent turbines, and self-cleaning pipes.

Schawlow, Arthur L.* (May 5, 1921-April 28, 1999): American. Schawlow received a share of the 1981 Nobel Prize in Physics for his work in laser spectroscopy.

Schick, Bela (July 16, 1877-December 6, 1967): Hungarian American. As well as conducting foundational research on allergies, Schick invented a test for diphtheria in 1913, which proved important to public health.

Schick, Jacob* (September 16, 1877-July 3, 1937): American. Schick simplified the chore of shaving with his invention of the electric razor, introduced in 1931.

Schilling, Pavel (1786-1837): Estonian Russian. Schilling produced an electronically detonated mine in 1812 and an early form of electromagnetic telegraphy in 1832.

Schmidt, Bernhard Voldemar* (March 30, 1879-December 1, 1935): Estonian German. Schmidt's telescope, invented in 1930, allowed a large field of view without the distortion of traditional Newtonian telescopes.

Schönbein, Christian Friedrich (October 18, 1799-August 29, 1868): German. Schönbein discovered ozone in 1840 and synthesized guncotton (nitrocellulose), which is used in explosives, in 1845.

Schweigger, Johann Salomo Christoph (April 8, 1779-September 6, 1857): German. Schweigger invented the needle galvanometer in 1820 to measure the force and direction of electric current.

Schwinn, Ignaz* (April 1, 1860-1948): German American. An innovative manufacturer, Schwinn became the leading maker of bicycles in the United States and the first to sell balloon-tire models, starting with the Aerocycle in 1934, and European-style racing models in the 1960's.

Scott, Arthur Hoyt (March 16, 1875-February 25, 1927): American. In 1907, the Scott Paper Company, under the leadership of Scott, the founder's son, introduced paper towels to the American public.

Seaborg, Glenn Theodore* (April 19, 1912-February 25, 1999): American. Seaborg shared the 1951 Nobel Prize in Chemistry for synthesizing transuranic elements and was the first scientist to chair the Atomic Energy Commission.

Seeberger, Charles (1857-September 12, 1931): American. Seeberger oversaw construction of his design for an escalator at the Otis Elevator Company in 1899.

Seguin, Marc (April 2, 1786-February 24, 1875): French. In the mid-1820's, Seguin built the first European wire-cable suspension bridge, which crossed the Rhone River at Tournon, France.

Seiwald, Robert J. (b. March 26, 1925): American. Seiwald and Joseph Burkhalter synthesized isothiocyanate compounds, the first labeling agents for human antibodies, which made possible rapid, accurate identification of infectious diseases.

Sellers, Coleman (January 28, 1827-December 28, 1907): American. A pioneer in using artificial light for photography, Sellers also designed the first large electrical dynamos for the Niagara Falls power plant.

Sellers, William (September 19, 1824-January 24, 1905): American. The inventor of a variety of machinery and machining tools, Sellers is best known for his spiral-geared planer, patented in 1862, and the American standard screw thread (1864).

Semmelweis, Ignaz (July 1, 1818-August 13, 1865): Hungarian. Semmelweis was a pioneer of antiseptic policy; in 1847, he established that puerperal (childbed) fever was contagious but that infections could be reduced by hand washing.

Semon, Waldo L. (September 10, 1898-May 26, 1999): American. Semon invented a method to plasticize polyvinyl chloride in 1930, making it commercially more useful as vinyl, as well as creating other synthetic rubber compounds.

Senefelder, Aloys (November 6, 1771-February 26, 1834): German. Senefelder invented lithography (flat-surface printing) in 1796 and a process for color lithography in 1826.

Serrurier, Iwan (fl. early twentieth century): Dutch American. In 1924, Serrurier invented the Moviola, a film-editing machine that became basic equipment in the movie industry.

Sessler, Gerhard (b. February 15, 1931): German American. In 1962, Sessler and James E. West invented the foil electret microphone with high sensitivity and broad frequency range, and Sessler invented the silicon microphone in 1983.

Seversky, Alexander Procofieff de (June 7, 1894-August 24, 1974): Russian American. A designer of fighter planes and an air war theorist, de Seversky was granted a patent for the concept of air-to-air refueling in 1921.

Shannon, Claude Elwood* (April 30, 1916-February 24, 2001): American. Shannon contributed fundamentally to modern digital computing with his method of electronic switching and his work on information theory.

Sharp, Walter B. (December 12, 1870-November 28, 1912): American. With Howard Hughes, Sr., his business partner, Sharp designed the Sharp-Hughes Tool Company's Rock Bit for drilling oil wells.

Sheehan, John C.* (September 23, 1915-March 21, 1992): American. Sheehan facilitated the manufacture of pure penicillin and derivatives of it with his process for synthesizing the antibiotics.

Shen Kuo (1031-1095): Chinese. Shen described the magnetic needle compass in 1088 and discovered that magnetic north differs from true north (the north pole).

Shen Nung (fl. twenty-eighth century B.C.E.): Chinese. According to legend, Emperor Shen Nung invented tea in 2737 B.C.E.

Sherman, Patsy O'Connell* (September 15, 1930-February 11, 2008): American. Working for Minnesota Mining and Manufacturing Company (3M), Sherman helped develop such successful products as the Scotchgard textile protector, first marketed in 1956.

Shockley, William* (February 13, 1910-August 12, 1989): American. Shockley shared the 1956 Nobel Prize in Physics for the invention of the junction transistor, which transformed the electronics industry and hastened the trend of miniaturization.

Sholes, Christopher Latham* (February 14, 1819-February 17, 1890): American. Sholes produced the first commercially successful typewriter, patented in 1868, and designed the keyboard, still in use, known by the letters on the left side of the top row, QWERTY.

Shrapnel, Henry (June 3, 1761-March 3, 1842): English. Shrapnel, an artillery officer, invented the exploding case shell, adopted by the British military in 1803.

Shugart, Alan* (September 27, 1930-December 12, 2006): American. Shugart helped develop the first disk drive while working for International Business Machines (IBM) in 1955, a key advance on the way to personal computers.

Shukhov, Vladimir (August 28, 1853-February 2, 1939): Russian. Shukhov introduced hyperboloids, double-curve structures, to architecture for use in towers and roofs as well as the mathematical analysis to calculate their strength.

Shuman, Frank (1862-1918): American. In 1897, Shuman demonstrated a device that powered a small steam engine by heating ether vapor with reflected sunlight and using the vapor to drive a water pump.

Sickels, Frederick Ellsworth (September 20, 1819-March 8, 1895): American. Sickels's cutoff valve for steam engines, patented in 1842, improved their efficiency and usefulness to American industry.

Siebe, Augustus (1788-1872): German English. Siebe produced the closed diving suit, comprising a rubberized canvas suit and a helmet with a built-in valve, tested in 1840.

Siemens, Werner* (December 13, 1816-December 6, 1892): German. Siemens engineered early applications of electricity to telegraphy and participated in establishing international, underwater cable lines.

Siemens, William (April 4, 1823-November 10, 1883): German English. Siemens and his brother Friedrich patented their regenerative (open hearth) furnace in 1856. Heated by waste gas from coal, it was widely used in the steelmaking and glass industries.

Sikorsky, Igor* (May 25, 1889-October 26, 1972): Russian American. An aviation pioneer, Sikorsky designed and flew the first multiengine airplane in 1913 and was a principal developer of the helicopter industry.

Simjian, Luther-George (January 28, 1905-October 23, 1997): Armenian American. Simjian invented an early version of the automated teller machine (ATM) in the late 1930's but also produced a self-focusing camera, postage metering machine, and teleprompter, among others.

Simon, Juanito A. (b. 1948): Filipino. In 1995, Simon developed lubrication technology that greatly reduced friction in engines and increased efficiency.

Sīnā, Ibn (Avicenna) (c. 980-1037): Persian. Among the most illustrious natural philosophers of the Middle Ages, Ibn Sīnā published influential medical treatises that describe contagious and sexually transmitted diseases, advocate the use of quarantine, and insist upon quantifiable trials for new medications.

Singer, Isaac Merrit* (October 27, 1811-July 23, 1875): American. Singer's improvements to the sewing machine and his brilliant marketing plan made him a leading manufacturer.

Slagle, James R. (b. 1934): American. Slagle wrote the first computer symbolic integration program, SAINT, in 1961. It demonstrated that computers can solve the kinds of analogy problems given on IQ tests.

Slater, Samuel (June 9, 1768-April 21, 1835): English American. Slater built the first successful water-powered textile mill in 1793 and conceived the company-owned mill village to house its workers.

Slayter, Russell Games (December 9, 1896-October 15, 1964): American. Slayter, Dale Kleist, and Jack Thomas created the methods of mass producing affordable glass wool (fiberglass) during the 1930's.

Smith, George Albert (January 4, 1864-May 17, 1959): English. A magician and psychic, Smith was also a filmmaker and inventor. He built on the work of Edward Turner to produce a two-color motion-picture camera, patented in 1906.

Spaeth, Mary (b. December 17, 1938): American. Spaeth and D. P. Bortfield developed the tunable dye laser in 1966, which became important to the production of atomic isotopes.

Spallazani, Lazzaro (January 12, 1729-February 11 or 12, 1799): Italian. A founder of experimental biology, Spallazani achieved successful artificial insemination in dogs, demonstrating that spermatozoa and ovules must have contact.

Spangler, James Murray* (November 20, 1848-January 22, 1915): American. Spangler invented the electric suction sweeper, patented in 1908, and started a company that became the Hoover Company.

Spencer, Percy L.* (July 9, 1894-September 8, 1970): American. In 1945, while testing a high-powered magnetron, Spencer noticed that a nearby candy bar melted. This gave him the idea for the microwave oven, introduced two years later.

Sperry, Elmer Ambrose* (October 12, 1860 [baptized]-June 16, 1930): American. A versatile inventor, Sperry is best known for his improved gyrocompass and contributions to military programs before World War I.

Spikes, Richard B. (1882-1962 or 1963): American. Spikes invented a beer keg tap and automobile directional signal, but he is perhaps best known for his automatic gearshift (1932) and automatic safety brake system (1962).

Sprague, Frank J.* (July 25, 1857-October 25, 1934): American. Sprague developed the first commercially successful electric railway system and contributed innovations to the electric elevator.

Srinivasan, Rangaswamy* (b. February 28, 1929): Indian. Srinivasan's development of ablative photodecomposition (APD) of organic materials with ultraviolet radiation found applications in the manufacture of microcircuits and in laser eye surgery.

Stanley, William, Jr. (November 22, 1858-May 14. 1916): American. In 1886, Stanley invented an induction coil system for producing alternating current (AC). It became the basis for later transformers.

Steinmetz, Charles Proteus* (April 6, 1865-October 26, 1923): German. Steinmetz developed the mathematical basis for practical alternating current and the techniques of long-distance transmission of electricity.

Stephenson, George* (June 9, 1781-August 12, 1848): English. Stephenson built the first railway line for steam locomotives, of which his *Rocket* was a successful model. The gauge of his railroad track became the world's standard.

Sternbach, Leo H. (May 7, 1908-September 28, 2005): American. Sternbach synthesized a novel class of tranquilizers called benzodiazeprines, among them valium, introduced in 1963.

Stevens, John* (1749-March 6, 1838): American. Stevens built the first oceangoing steamboat in 1809 and the first American steam locomotive in 1825.

Stevens, Louis (b. April 15, 1925): American. With William A. Goddard and John Lynott, Stevens produced a magnetic disk drive in 1955.

Stevin, Simon (1548-1620): Dutch. Stevin formulated the law of inclined planes and laws of hydraulics, and in 1599 he described a twenty-six-seat, self-propelled land yacht—a carriage with sails for use on beaches.

Stibitz, George* (April 20, 1904-January 31, 1995): American. A visionary in uses for computers, Stibitz performed the first long-distance transfer of computer data in 1940.

Stirling, Robert* (October 25, 1790-June 6, 1878): Scottish. A minister and classical scholar, Stirling invented the Stirling hot-air engine with his brother James, patented in 1827.

Stodola, Aurel (May 10, 1859-December 25, 1942): Slovak. In 1915, Stodola and surgeon Ferdinand Sauerbruch created the first artificial hand, but Stodola is better known as an expert in thermodynamics and its application in designing steam and gas turbines.

Stokes, Rufus (1922 or 1924-1986): American. In 1968, Stokes patented an air-purification system for cutting gas and ash emissions from furnaces.

Strauss, Levi* (February 26, 1829-September 26, 1902): German American. Strauss created the quintessential Western wear with his "waist overalls" (blue jeans), patented in 1873.

Strite, Charles P. (fl. early twentieth century): American. Strite received a patent for the automatic toaster in 1921.

Sturgeon, William* (May 22, 1783-December 4, 1850): English. Sturgeon is credited with building the first electromagnet, and he invented an electric motor, galvanometer, and long-lasting battery cell.

Su Song (1020-1101): Chinese. Su built a water-powered astronomical clock tower that was the first device to use a continuous chain drive.

Sunatori, Simon (b. January 10, 1959): Canadian. Sunatori invented the MagneScribe three-in-one, auto-retractable pen and Magic Spicer, a self-sealing hanging dispenser.

Sundback, Gideon (1880-1954): Swedish Canadian. In 1913, Sundback invented the modern zipper of two facing rows of teeth joined by a slider.

Sutherland, Ivan (b. May 16, 1938): American. Sutherland pioneered computer graphics with the program Sketchpad in 1960 and contributed to three-dimensional computer modeling, visual simulations, and virtual reality.

Sveda, Michael (February 3, 1912-August 10, 1999): American. Sveda invented the noncaloric artificial sweetener cyclamate in 1937, widely used until 1969, when the U.S. government banned it on suspicion that it was a carcinogen.

Svedberg, Theodor* (August 30, 1884-February 25, 1971): Swedish. The 1926 Nobel laureate in chemistry, Svedberg invented the ultracentrifuge in 1924, which is capable of separating out very small particles, and a device for measuring low osmotic pressure.

Swan, Joseph Wilson* (October 31, 1828-May 27, 1914): English. Swan was the first to patent an incandescent lamp, which he demonstrated in 1878, and contributed to the development of photographic printing.

Szilard, Leo* (February 11, 1898-May 30, 1964): Hungarian American. Szilard conceived the chain reaction necessary for nuclear reactors and bombs. He also developed a refrigerator in collaboration with Albert Einstein.

T

Tabern, Donalee L. (January 27, 1900-December 31, 1974): American. In 1936, Tabern and Ernest Volwiler synthesized pentothal, a general anesthetic widely used in surgery.

Tainter, Charles (April 25, 1854-April 20, 1940): American. With Alexander Graham Bell and Chichester A. Bell, Tainter produced an improved phonograph, the graphophone, patented in 1886. Later, Tainter modified it to take dictation: the Dictaphone.

Talbot, William Fox (February 11, 1800-September 17, 1877): English. In 1834 and 1835, Talbot experimented with paper coated with salt and silver nitrate until he had created a negative photographic image, from which many positive prints could be made, known as the collotype process.

Tamm, Igor (July 8, 1895-April 12, 1971): Russian. A 1956 Nobel laureate in physics, Tamm was also a central theoretician behind the first Soviet thermonuclear bomb and attempts to use fusion peacefully with the tokamak system.

Tanaka, Toyoichi* (January 4, 1946-May 20, 2000): Japanese American. Following Tanaka's discovery of "smart gels," scientists were able to track microscopic changes in a macroscopic way; the polymer gels also had a wide range of practical applications.

Taylor, Charles E.* (May 24, 1868-June 30, 1956): American. Taylor built the engines that Orville and Wilbur Wright used in their first few airplanes.

Taylor, Frederick W. (March 20, 1856-March 21, 1915): American. Taylor developed a business structure strategy, known as scientific management, that emphasized precise production procedures based upon analysis of workflows and thorough managerial control.

Teetor, Ralph (1891-1982): American. Teeter was granted the first patent for a cruise-control device for automobiles, Speedostat.

Telford, Thomas (August 9, 1757-September 2, 1834): Scottish. Telford was a civil engineer who built aqueducts, canals, roads, and bridges, including the Menai Bridge (completed 1826), then the longest suspension bridge in the world.

Telkes, Maria* (December 12, 1900-December 2, 1995): Hungarian American. Telkes is noted for developing diverse applications of solar energy, including a solar still, a solar oven, and even a completely solar home.

Tellegen, Bernard D. H. (June 24, 1900-August 30, 1990): Dutch. In 1926, Tellegen invented the pentode valve, an electronics component containing five electrodes, used in radios.

Teller, Edward* (January 15, 1908-September 9, 2003): Hungarian American. Teller played a leading role in the design and development of the fusion bomb and vigorously argued that it should be part of the United States' arsenal of weapons.

Temple, Lewis (1800-May, 1854): American. Temple's Toggle, which he invented in 1848, was a harpoon with a pivoting head that did not come dislodged when whales spun or thrashed after being speared.

Terry, Eli (April 13, 1772-February 26, 1852): American. Terry held several patents for clocks, including the first that the U.S. Patent Office granted for a clock (1797), and he pioneered their mass production.

Tesla, Nikola* (July 9/10, 1856-January 7, 1943): Serbian American. Tesla brought many theoretical and applied innovations to electromagnetism, notably his brushless alternating current induction motor (1888).

Theiler, Max (January 30, 1899-August 11, 1972): South African. Theiler received the 1951 Nobel Prize in Physiology or Medicine for creating a vaccine against yellow fever.

Thomas, Valerie L.* (b. February 1, 1943): American. A mathematician working for the National Aeronautics and Space Administration (NASA), Thomas invented the illusion transmitter, patented in 1980, which conveys three-dimensional images.

Thompson, Benjamin* (March 26, 1753-August 21, 1814): English. Thompson (Count Rumford) was a leading scientific investigator of his day and invented an improved oven, lamp, and fireplace and a drip coffee maker.

Thompson, John T.* (December 31, 1860-June 21, 1940): American. With Theodore Eickhoff and Oscar Payne, Thompson created the Thompson submachine gun in 1919.

Thompson, Robert (1822-1873): Scottish. In 1845, Thompson devised a pneumatic tire—a hollow band of rubber, inflated, around a steel wheel—in order to reduce shocks and vibrations for carriages.

Thomson, Elihu* (March 29, 1853-March 13, 1937): American. Thomson was a leading electrical engineer of his era, developing light and power systems in the United States, the United Kingdom, and France.

Tiffany, Louis Comfort (February 18, 1848-January 17, 1933): American. Tiffany created Favrile stained glass following experiments that began in 1875. It was among the first innovations of the Art Nouveau style.

Tigerstedt, Eric (1887-1925): Finnish. Tigerstedt developed the first sound-on-film technology for "talking pictures" in 1914.

Tihanyi, Kálmán (April 28, 1897-February 26, 1947): Hungarian. Tihanyi was a coinventor of the cathode-ray tube and iconoscope and developed remote-controlled mines and aircraft.

Tilghman, Benjamin Chew (October 26, 1821-July 3, 1901): American. In 1866, Tilghman developed a sulfite process to pulp wood for papermaking; in 1870, he invented sandblasting.

Tipu Sultan (November 20, 1750-May 4, 1799): Indian. A leader in the resistance to British occupation of India, Tipu Sultan, the "Tiger of Mysore," invented the tactic of mass rocket attacks on enemy infantry.

Tishler, Max* (October 30, 1906-March 18, 1989): American. Tishler led research into the synthesis of ascorbic acid (vitamin C), cortisone, riboflavin, vitamin B_{12}, streptomycin, and other compounds valuable to medicine.

Torricelli, Evangelista* (October 15, 1608-October 25, 1647): Italian. A mathematician and physicist, Torricelli invented the barometer in 1644.

Townes, Charles Hard* (b. July 28, 1915): American. Townes invented microwave amplification by stimulated emission of radiation (maser), a precursor of the laser. For it he shared the 1964 Nobel Prize in Physics.

Toyoda, Sakichi* (February 14, 1867-October 30, 1930): Japanese. From 1890 to 1925, Toyoda revolutionized Japanese industry with his power looms, and he provided the seed money for his son to start Toyota Motor Company.

Traeger, Alfred (August 2, 1895-July 31, 1980): Australian. Traeger invented a radio whose generator was run by pedal power, introduced in 1929 for medical communications in Australia's remote communities.

Trevithick, Richard* (April 13, 1771-April 22, 1833): English. Trevithick developed a steam locomotive whose power plant, when used for stationary applications, was known as the Cornish engine.

Trkman, Franc (1903-1978): Slovenian. Among Trkman's inventions were an electrical switch for hot plates, a key-making process, and watertight windows.

Tsiolkovsky, Konstantin* (September 17, 1857-September 19, 1935): Russian. A visionary advocate of space travel, Tsiolkovsky designed space stations and rocket-powered vehicles with life-support systems.

Tsvet, Mikhail (May 14, 1872-June 26, 1919): Italian Russian. In 1901, Tsvet pioneered chromatography, a technique for separating chemical mixtures and analyzing them.

Tull, Jethro* (March 30, 1674 [baptized]-February 21, 1741): English. Tull's invention of the seed drill multiplied crop yields and improved weed control, inaugurating the late eighteenth century agricultural revolution in England.

Tupolev, Andrei Nikolayevich* (November 10, 1888-December 23, 1972): Russian. Tupolev designed more than one hundred military and civilian aircraft.

Tupper, Earl S.* (July 28, 1907-October 5, 1983): American. Thanks to Tupper's innovative marketing strategy based upon home sales parties, his Tupperware plastic containers became the standard for household food storage beginning in the 1950's.

Turing, Alan Mathison* (June 23, 1912-June 7, 1954): English. Turing conceived the basic ideas behind the design of early computers and created the Turing test to distinguish computing from human intelligence.

Twain, Mark* (November 30, 1835-April 21, 1910): American. Born Samuel Langhorne Clemens, Twain was an inventor as well as a writer. The most successful of his three patented inventions was the self-pasting scrapbook, which had adhesive on the pages so items could be directly attached.

Tyndall, John* (August 2, 1820-December 4, 1893): Irish. An early atmospheric scientist, Tyndall conceived the idea of the "atmospheric envelope," which implied that sunlight could be trapped in Earth's atmosphere (the greenhouse effect). He also developed a respirator for firefighters in 1871.

U

Upjohn, William Erastus (June 5, 1853-October 18, 1932): American. A founder of the American pharmaceutical industry, Upjohn invented dissolvable pills and in 1884 a machine to mass-produce them.

Urry, Lewis* (January 29, 1927-October 19, 2004): Canadian. Urry's invention of the long-lasting alkaline battery significantly extended the operational lifetime and reliability of innumerable electrical devices.

V

Vallino, Lisa (b. 1916): American. In 1993 Vallino and her mother, Betty Rozier, patented the "IV House," a plastic shield that protects the site of an intravenous line during medical care.

Van de Graaff, Robert Jemison (December 20, 1901-January 16, 1967): American. The Van de Graaff generator (1929), standard equipment in school physics labs, accumulates electrical charge on a moving belt and deposits it in a hollow glass sphere at the top.

Van Doorne, Hub (1900-1979): Dutch. Van Doorne developed the continuously variable truck transmission, introduced in 1959.

Van Houten, Coenraad Johannes (1801-1887): Dutch. In 1822, Van Houten invented a press to remove cocoa oil, leaving cocoa powder, soon to spread through the Western world in everything from chocolate bars to chocolate milk.

Van Kannel, Theophilus (1841-December 24, 1919): American. Van Kannel invented the revolving door in 1888.

Vaucanson, Jacques de* (February 24, 1709-November 21, 1782): French. Vaucanson invented machine tools, such as the punch card, and tool-making machinery, which significantly contributed to the automation of manufacturing.

Vitullo, Louis R. (1924-January 3, 2006): American. A police detective, in the 1970's Vitullo developed the standard evidence kit to detect sexual assault.

Vo-Dinh, Tuan (b. 1948): Vietnamese American. Vo-Dinh invented several medical sensors based on synchronous luminescence technology that can identify toxins, gene mutations, or disease by optical scanning.

Vogel, Orville (May 19, 1908-April 12, 1991): American. Vogel developed semidwarf wheat varieties. First released to farmers in the 1960's, they were part of the Green Revolution in agriculture.

Volta, Alessandro* (February 18, 1745-March 5, 1827): Italian. Volta is best known for inventing the voltaic pile, an electric battery, in 1799, but he also produced several instruments, such as a eudiometer for measuring the purity of air.

Von Neumann, John (December 28, 1903-February 8, 1957): Hungarian American. A leading mathematician of the twentieth century, von Neumann invented game theory and worked out the basis for computer architecture, among many other diverse achievements.

Vrančić, Faust* (1551-January 17, 1617): Croatian. A man of wide-ranging interests, Vrančić published *Machinae novae* (new machines) in 1595; it contained the first printed design of a parachute.

W

Waksman, Selman Abraham* (July 22, 1888-August 16, 1973): Russian American. From his studies of soil microorganisms, Waksman developed numerous antibiotics, most notably streptomycin (1943), which greatly enhanced public health worldwide. He received the 1952 Nobel Prize in Physiology or Medicine for his work.

Walker, Madam C. J.* (December 23, 1867-May 25, 1919): American. Born Sarah Breedlove, Walker reinvented herself. Her business and marketing strategies for selling her hair care products enabled women, African Americans in particular, to become financially independent.

Walker, Hildreth, Jr. (b. 1933): American. Walker developed laser systems for the military and civilian use, for instance leading the team that used a laser to measure the distance to the Moon during the Apollo 11 mission.

Wallis, Barnes (September 26, 1887-October 20, 1979): English. Wallis was the first to use the geodesic design in aircraft but is better known for inventing the bouncing bomb in 1943, used for dam busting in World War II.

Walsh, Sir Alan* (December 19, 1916-August 3, 1998): English. Walsh invented atomic absorption spectroscopy, enabling scientists to identify quickly the chemical elements present in a sample.

Walton, Ernest Thomas Sinton* (October 6, 1903-June 25, 1995): Irish. Working with John Cockroft, Walton built the first high-energy particle accelerator in 1932 and produced the first human-made nuclear reaction. They shared the 1951 Nobel Prize in Physics for their work.

Walton, Mary (fl. late nineteenth century): American. In 1879, Walton invented a device to reduce emissions from smokestacks by running the smoke through water tanks, and in 1881 she developed a sound-dampening system for elevated commuter trains.

Wang, An* (February 7, 1920-March 24, 1990): Chinese American. A leading entrepreneur in the computer industry, in 1955 Wang patented a device that made magnetic core memory possible.

Wang, Taylor Gunjin* (b. June 16, 1940): Chinese American. Wang became the first Chinese American astronaut when he flew on the space shuttle *Challenger* in 1985, before which he invented novel methods of acoustic manipulation of matter and designed drop dynamics experiments in zero gravity.

Wankel, Felix* (August 13, 1902-October 9, 1988): German. The Wankel rotary engine, designed in 1954, operates by using orbiting triangular rotors that perform the function of pistons in conventional gasoline engines.

Warner, Ezra J. (1841?-1910?): American. Warner patented the can opener in 1858. It was first widely used during the Civil War.

Waterman, Lewis* (November 20, 1837-May 1, 1901): American. Waterman patented his fountain pen, the first to be leakproof and to operate reliably, in 1884.

Watson-Watt, Sir Robert Alexander* (April 13, 1892-December 5, 1973): Scottish. Watson-Watt developed the physics of radar, and his administrative efforts helped in producing a radar-based air defense system during World War II.

Watt, James* (January 19, 1736-August 25, 1819): Scottish. Watt's innovations in the steam engine, such as a separate condenser allowing faster, more efficient operation, fostered the Industrial Revolution.

Wedgwood, Thomas (May 14, 1771-July 11, 1805): English. With Sir Humphry Davy, Wedgwood invented a method for temporarily fixing images on glass coated with silver nitrate, described in 1802.

Welsbach, Carl Auer von (September 1, 1858-August 4, 1929): Austrian. In 1890, von Welsbach invented an efficient mantle for gas lamps. In 1898, he developed an osmium-tungsten filament for incandescent light bulbs.

Wenström, Jonas (1855-1893): Swedish. In 1880, Wenström invented the slotted armature for electric motors, which improved efficiency.

Westinghouse, George* (October 6, 1846-March 12, 1914): American. A prolific inventor and vigorous entrepreneur, Westinghouse made his fortune initially with an air brake system for trains.

Weston, Edward (May 9, 1850-August 20, 1936): English American. West held hundreds of patents but is best known for his portable voltmeter (1886), which measured electrical current.

Wetzel, Don* (b. 1928): American. Wetzel designed a successful automated teller machine (ATM), introduced in 1969, and conceived the management concepts to make it profitable for banks.

Wheatstone, Charles* (February 6, 1802-October 19, 1875): English. A physicist who produced inventions in acoustic and telegraph technology, Wheatstone invented an eerie musical instrument, the enchanted lyre (or acoucryptophone) in 1821.

Whipple, Squire (December 16, 1804-March 15, 1888): American. Whipple invented the iron truss for bridges in 1841, and his 1847 *A Work on Bridge Building* was the first thorough scientific study of bridge construction.

Whitcomb, Richard T. (b. February 21, 1921): American. Whitcomb, an engineer for the National Aeronautics and Space Administration (NASA), is best known for creating the supercritical airfoil in the 1970's and vertical wing-tip winglets that reduce drag.

Whitney, Eli* (December 8, 1765-January 8, 1825): American. Most famously the inventor of the cotton gin for stripping cottonseed from the fiber, Whitney also introduced interchangeable parts in the manufacture of firearms.

Whittle, Sir Frank* (June 1, 1907-August 8, 1996): English American. Whittle designed, built, and in 1937 tested a turbojet engine that helped launch the jet age.

Wichterle, Otto* (October 27, 1913-August 18, 1998): Czech. Wichterle discovered the hydrogel polyhydroxyethyl methacrylate (poly-HEMA) in 1952 and in 1957 how to mold it into flexible contact lenses.

Widnall, Sheila* (b. July 13, 1938): American. Widnall revolutionized her specialty, fluid dynamics, in her work on aircraft turbulence, vortices, and spiraling airflows.

Wilcox, Stephen (February 12, 1830-November 27, 1893): American. Wilcox and George Babcock devised a safety water-tube boiler in 1856 and a steam generator in 1867.

Williams, Robert R., Jr. (February 16, 1886-October 2, 1965): American. Williams isolated vitamin B_1 (thiamine) in 1933 and two years later found a method to synthesize it.

Williams, Sam (b. May 7, 1921): American. In 1968, Williams patented his small fanjet engine, forerunner to the engines that propel cruise missiles.

Wilmut, Ian (b. June 7, 1944): Scottish. In 1996, Wilmut became the first scientist to clone a mammal, a Finn Dorset ewe named Dolly, from differentiated adult mammary cells.

Winchell, Paul* (December 21, 1922-June 24, 2005): American. Best known as a television entertainer, Winchell was also an inventor. He designed an artificial heart, patented in 1963, that was a forerunner of the Jarvik-7 heart.

Winton, Alexander* (June 20, 1860-June 21, 1932): American. The Winton Motor Carriage Company was among America's first automobile manufacturers, and Winton introduced the first American diesel engine and the first marine engines.

Wong-Staal, Flossie (b. 1947): Chinese American. Wong-Staal cloned the HIV virus in 1985 and was the first person to determine its structure.

Wood, A. Baldwin (1879-1956): American. Wood invented hydraulic equipment, including the low-maintenance, efficient Wood screw pump (1913), which was used to drain water from New Orleans.

Woods, Granville T.* (April 23, 1856-January 30, 1910): American. Among Woods's sixty or so patents were an egg incubator, emergency braking systems for subways, and the synchronous multiplex railway telegraph, which improved communications between train crews and stations.

Woodward, Robert Burns (April 10, 1917-July 8, 1979): American. Woodward received the 1965 Nobel Prize in Chemistry for his work in organic chemistry, including his synthesis of complex substances, such as cholesterol, cortisone, vitamin B_{12}, and quinine.

Wouk, Victor (1919-May 19, 2005): American. Wouk was an early advocate of hybrid cars, converting a Buick Skylark in 1972, and held numerous patents in hybrid and electric car technology.

Wozniak, Steve* (b. August 11, 1950): American. A cofounder of Apple Computer in 1976, Wozniak led the design of the Apple II personal computer and produced several other key technological innovations in microcomputing.

Wright, Frank Lloyd* (June 8, 1867-April 9, 1959): American. Wright transformed American architecture during his nearly seventy-five-year career and was responsible for many innovations in structure and materials.

Wright, Wilbur and Orville* (April 16, 1867-May 30, 1912 [Wilbur]; August 19, 1871-January 30, 1948 [Orville]): American. The heavier-than-air Wright Flyer, piloted by Orville, lifted a human in powered flight for the first time at Kitty Hawk, North Carolina, on December 17, 1903.

Wynne, Arthur (1862-1945): English American. Wynne invented the crossword puzzle in 1913.

Y

Yablochkov, Pavel (September 14, 1847-March 31, 1894): Russian. The Yablochkov candle, invented in 1876, was the first practical arc lamp.

Yagi, Hidetsugu (1886-1976): Japanese. Yagi and Shintaro Uta patented the Yagi Antenna in 1926. Its simple structure and high performance made it useful in a variety of systems, including radio and radar.

Yalow, Rosalyn* (b. July 19, 1921): American. Yalow received the 1977 Nobel Prize in Physiology or Medicine for developing the radioimmunoassay (RIA), which detects small concentrations of compounds, such as hormones, in body fluids.

Yi Xing (683-727): Chinese. Yi Xing invented the escapement mechanism (permitting a regulated escape of energy from a spring or weight) for his water clock, built about 725.

Yokoi, Gumpei (September 10, 1941-October 4, 1997): Japanese. Yokoi created the Nintendo Game Boy and was part of the team that developed the Nintendo Entertainment System.

Young, Arthur M. (1905-1995): American. Young designed Bell Helicopter's first helicopter, the Model 30, first tested in 1946, and patented a flybar (rotor stabilizer bar).

Yunus, Muhammad (b. June 28, 1940): Bangladeshi. Founder of the Grameen Bank and recipient of the 2006 Nobel Peace Prize, Yunus introduced microcredit, loans tailored to entrepreneurs who do not qualify for traditional loans.

Z

Zaid, Hajib (b. 1951): Palestinian American. Zaid patented his corrosion inhibitor industrial chemical mixtures in 1987. Mixtures of oil- and water-soluble compounds, they keep oil wells and pipes free from bacteria and corrosion.

Zamboni, Frank (September 16, 1901-July 27, 1988): American. In 1949, Zamboni invented an ice-resurfacing machine for ice-skating rinks that afterward was known by his name.

Zara, Gregorio Y. (March 8, 1902-October 15, 1978): Filipino. Zara produced a two-way telephone-television, or videophone, in 1955.

Zelinsky, Nikolay (1861-1953): Russian. In 1902, Zelinsky helped develop a method to classify and purify oil; in 1915, he invented an activated charcoal mask.

Zeppelin, Ferdinand von* (July 8, 1838-March 8, 1917): German. Zeppelin pioneered the powered lighter-than-air vehicle, flying his first giant dirigible in 1900.

Ziegler, Karl (November 26, 1898-August 12, 1973): German. Ziegler shared the 1963 Nobel Prize in Chemistry for developing catalysts that are widely used in the plastics industry.

Zinsser, Hans (November 17, 1878-September 4, 1940): American. In 1932, Zinsser proved that typhus is caused by the microorganism *Rickettsia prowazekii* and with M. Ruiz Castañeda developed a vaccine.

Zsigmondy, Richard* (April 1, 1865-September 24, 1929): Austrian German. Zsigmondy developed the ultramicroscope in 1903 for his foundational investigation into colloids, for which he received the 1925 Nobel Prize in Chemistry.

Zuse, Konrad* (June 22, 1910-December 18, 1995): German. Zuse designed and built early computers and wrote the first book about digital physics.

Zworykin, Vladimir* (July 30, 1889-July 29, 1982): Russian American. Considered by some as the "true inventor of the television," Zworykin demonstrated his television camera, the iconoscope, and its receiver, the kinescope, in 1929.

ELECTRONIC RESOURCES

WEB SITES

The following sites were visited by the editors of Salem Press in 2009. Because URLs frequently change, the accuracy of these addresses cannot be guaranteed; however, long-standing sites, such as those of colleges and universities, national organizations, and government agencies, generally maintain links when sites are moved or updated.

About.com: Inventors
http://inventors.about.com/

About.com Inventors provides a great deal of useful information for would-be inventors and anyone else who is interested in inventions. The "Famous Inventions: A to Z" page contains an alphabetical list of inventions, from adhesive glue through the Zamboni ice resurfacing machine, with links to a separate page of information for each invention. Similarly, "Famous Inventors: A to Z" offers an alphabetical listing of investors with links to pages containing biographical information about them and descriptions of their inventions. "Black History Month" focuses on African American inventors and patent holders, including Benjamin Banneker, George Washington Carver, and Madam C. J. Walker. Users also can access a wide range of time lines, including chronologies of inventions from the fifteenth through the twenty-first centuries, as well as chronologies of specific inventions, technologies, and inventors' lives. Advice for prospective investors, including information about patents, trademarks, and marketing, also is available.

The Alexander Graham Bell Family Papers at the Library of Congress, 1862-1939
http://memory.loc.gov/ammem/bellhtml/bellhome.html

A collection of almost 4,700 archival items, containing more than 51,000 images, that chronicle Bell's invention of the telephone and involvement in the first telephone company, as well as his family life, interest in education for the deaf, and aeronautical and other scientific research. Users can access a range of digitized materials, including selected correspondence, scientific notebooks, journals, blueprints, and photographs. The experimental notebook from March 10, 1876, describing Bell's first successful experiment with the telephone, during which he spoke through the new invention to his assistant the famous words, "Mr. Watson—Come here—I want to see you," is included in the collection.

Canadian Patents Database
http://patents.ic.gc.ca/cipo/cpd/en/introduction.html

This page is part of the official site of the Canadian Intellectual Property Office and enables users to retrieve more than seventy-five years of patent descriptions and images. Four search engines provide a variety of ways to access this material.

Computer History Museum: Online Exhibits
http://www.computerhistory.org/exhibits/

The museum, located in Mountain View, California, maintains a time line of computer history and a number of online exhibits on its Web site. "The Babbage Engine" describes Charles Babbage's invention of the first automatic computing engine. "The Silicone Empire" chronicles the history of semiconductors in computers. "Selling the Computer" is a collection of computer company marketing brochures. Other exhibits outline Internet history from 1962 through 1992, provide an overview of the microprocessing industry from 1971 through 1996, and display images of computing artifacts. Additional information about inventors and other computer industry leaders can be found in the biographies of the persons who have been inducted into the museum's Hall of Fame.

Early Office Museum
http://www.officemuseum.com/

A virtual museum that chronicles the evolution of the business office, office machinery and equipment, and business technology. The exhibits include vintage photographs and other images of offices from the 1770's through the 1950's and displays of antique typewriters, adding machines and calculators, copying machines, staplers, fasteners, paper clips, and writing implements.

Emile Berliner and the Birth of the Recording Industry
http://memory.loc.gov/ammem/berlhtml/berlhome.html

A record of the life and work of Emile Berliner, inventor of the microphone and the flat recording disc gramophone player. The site features selected correspondence, articles, lectures, speeches, photographs, and other items from Berliner's papers. Its most interesting feature, however, is its access to more than one hundred early sound recordings that users can listen to via RealPlayer, Media Player, QuickTime, and other MP3 players. The recordings are organized by category, such as band and orchestra, instrumentalists, spoken comedy, popular music vocalists and vocal groups, classical and opera, spoken word, and foreign language, and include a rendition of "Stars and Stripes Forever" by the Sousa Band and Buffalo Bill's lecture "Sentiments on the Cuban Question."

Famous Black Inventors
http://www.black-inventor.com/

An easy-to-use site containing eighteen biographies of black inventors and descriptions of their inventions. Some of the inventors are George Edward Alcorn, creator of the imaging X-ray spectrometer, blood bank inventor Charles Richard Drew, and Garrett Augustus Morgan, who invented a gas mask and traffic light. The site links to other resources related both to African American inventors and to other aspects of invention.

Famous Women Inventors
http://www.women-inventors.com/

Similar to Famous Black Inventors (above), this site contains nineteen biographies about women inventors and their creations; among these women are Mary Anderson, the inventor of windshield wipers, disposable diapers inventor Marion Donovan, and actress Hedy Lamarr, who helped create a wireless communication system to combat the Nazis in World War II. The site offers links to other Web resources with information about invention in general and women inventors in particular.

The Great Idea Finder
http://www.ideafinder.com/history/

While some of its information is aimed at children, The Great Idea Finder is a comprehensive, user-friendly source of information for anyone interested in inventions. Its "Invention Facts and Myths" section contains information about inventions that can be retrieved via an alphabetical listing of invention titles; information also can be accessed via a list of invention categories, including "Everyday Life History," which describes the histories of apparel, food and drink, household items, toys and games, and office equipment. Other sections of the site feature inventor biographies and pages of information about inventors from Canada, France, Germany, and several other nations. The "Innovation Timeline" chronicles inventions created from ancient times to the present day. The "Resources Center" is especially useful because it offers recommendations for numerous Web sites, books, and videos about inventors and inventions.

Inside an American Factory: Films of the Westinghouse Works, 1904
http://memory.loc.gov/ammem/papr/west/westhome.html

Users can view twenty-one "actuality films" depicting the working conditions at the Westinghouse Air Brake, Westinghouse Electric and Manufacturing, and Westinghouse Machine companies. The exterior and interior shots of the factories, along with employees performing their tasks, were meant to highlight the companies' operations. The site also provides a biography of George Westinghouse, a time line of his life and inventions, and a discussion of working conditions at his factories.

Inventing Entertainment: The Motion Pictures and Sound Recordings of the Edison Companies
http://memory.loc.gov/ammem/edhtml/edhome.html

Focusing on Thomas Alva Edison's contributions to the entertainment industry, this site provides access to 341 motion pictures filmed by his company and eighty-one disc sound recordings designed to be played on the Edison disc phonograph. Users can find these films via indexes of their titles, genres, or years they were produced, as well as through a list of their subjects; the selected disc recordings are accessible via indexes of their titles or genres. The site describes what computerized equipment users need to view the motion pictures and to hear the recordings, as well as offering an Edison biography and a time line of his life that links to additional information about his entertainment-related inventions.

Invention Now: National Inventors Hall of Fame Foundation Inc.

http://www.invent.org

Invention Now is a nonprofit organization that aims to foster the spirit of invention by maintaining the National Inventors Hall of Fame. The hall honors men and women who are, in the words of the site, "responsible for great technological advances that make social and economic progress possible." Inventors are inducted annually, and as of January, 2009, almost four hundred people had been included. The Web site provides a database that allows users to obtain information via lists of inventors, inventions, dates of induction to the Hall of Fame, and the decade in which an invention was patented. Users also can obtain information by "channel," or category of invention, such as agriculture, electricity, medical, and chemistry. In addition, the site provides information about the National Inventors Hall of Fame Museum, located in Akron, Ohio, and Invention Now's other programs.

Lemelson Center for the Study of Invention and Innovation

http://invention.smithsonian.org/home

Since 1995, the center has been housed at the Smithsonian Institution's National Museum of American History. The center's Web site provides a range of virtual information about inventors and inventions that is contained in the "Centerpieces" section. These virtual exhibits include "Inventing Ourselves," a description of inventions that are wearable or able to be implanted in the human body, including running shoes and nutritional supplements; "Doodles, Drafts, and Designs," a selection of industrial drawings from the Smithsonian's archives, including designs for an electromechanical flycatcher, tennis racket, and Binney and Smith's Crayola crayons; "Whole Cloth," a history of the American textile industry; and exhibits explaining the invention of the electric guitar and the quartz watch. An extensive "Resources" section includes links to Web sites, a bibliography of books about invention, and access to information from the National Museum of American History Archives Center.

The Medieval Technology Pages

http://scholar.chem.nyu.edu/tekpages/Technology.html

Paul J. Gans, a chemistry professor at New York University, created and maintains these pages, which provide referenced information on technological innovation and related subjects in western Europe during the Middle Ages. The information can be accessed in three ways: The "Subjects Index "is an alphabetical list of medieval inventions with links to pages about agricultural tools, cannons, soap, the wine press, and other inventions of the era. "Timeline Epochs" provides a chronological listing of inventions created from 500 through 1600. "References" is a bibliography of print resources about medieval technology.

The Museum for the Preservation of Elevating History

http://www.theelevatormuseum.org/

Created by the founder and former editor of *Elevator World* magazine, this virtual museum chronicles, in its own words, "how lifting evolved through the ages." The museum's virtual wings provide information about the genesis of lifting, the creation of powered-mechanical systems, the age of electric power, and the major components of the elevator; another wing focuses on the various inventors of the elevator, including Michael Faraday, Jesse W. Reno, and Elisha Graves Otis. A time line of lifting-related technology from 4500 B.C.E. to 1948 C.E. also is available.

Samuel F. B. Morse Papers at the Library of Congress, 1793-1919

http://memory.loc.gov/ammem/sfbmhtml/sfbmhome.html

This digitized collection comprises about 6,500 items that chronicle Morse's invention of the telegraph, his participation in the development of telegraph companies in the United States and abroad, and other aspects of his life and career. Some of the items include correspondence, diaries, scrapbooks, and maps; the highlight of the collection is the original paper tape of the first telegraph message, "What hath God wrought?," that was sent on May 24, 1844. The site also features a time line of significant events in Morse's life and a Morse family tree.

Smith College History of Science: Museum of Ancient Inventions

http://www.smith.edu/hsc/museum/ancient_inventions/home.htm

This Web site was created by Smith College students enrolled in a course on ancient inventions. It is a virtual museum, whose exhibits consist of forty-five inventions created from antiquity through 1700, including woven cloth, eyeliner, and the tumbler lock. Each invention is displayed on a separate page containing descriptions and photographs.

United States Patent and Trademark Office
http://www.uspto.gov/

A division of the Department of Commerce, the U.S. Patent and Trademark Office (USPTO) is the federal agency authorized to patent inventions. The agency's Web site includes a separate page (http://www.uspto.gov/main/patents.htm) providing information about the patent process, including basic facts about patents, how to get a patent, and the types of patents available; inventors can use the site to file an online patent application. The page also offers access to information about trademarks, service laws, copyrights, and patent laws and regulations. Users can search the site's database to locate full-page images of patents issued from 1790 through 1975, the full text of patents issued since 1976, and patent applications published since March, 2001.

The Wilbur and Orville Wright Papers at the Library of Congress
http://memory.loc.gov/ammem/wrighthtml/wrighthome.html

A digitized collection of more than 10,120 items, including correspondence, diaries, and notebooks, that chronicles the lives of the two brothers and their work leading to the first successful flight of their airplane at Kitty Hawk, North Carolina, on December 17, 1903. Among the site's items are the brothers' collection of glass-plate photograph negatives. A time line about the brothers' lives and work is also featured.

The Wright Brothers and the Invention of the Aerial Age
http://www.nasm.si.edu/wrightbrothers/

In 2003, the Smithsonian Institution's National Air and Space Museum mounted an exhibition to commemorate the centennial of the first successful flight of the Wright brothers' airplane. Some of the information from that exhibit remains available on this Web site and is organized by three categories: "Who Were Wilbur and Orville?" provides biographical information about the brothers. "Inventing a Flying Machine" highlights the research the brothers conducted in order to create the first successful powered airplane in 1903 and a refined version of that plane two years later. "The Aerial Age Begins" documents the scientific and social impact of the brothers' invention, with information about competing aeronautical inventions, the brothers' airplane manufacturing company, and how the airplane became part of popular culture.

Zoom Inventors and Inventions
http://www.enchantedlearning.com/inventors/indexa.shtml

Created by Enchanted Learning, an organization that produces educational Web sites, Zoom Inventors and Inventions offers useful, easily accessible information, including descriptions of important inventions and capsule biographies of inventors. Users can access a series of time lines chronicling inventions from ancient times through 2000 or can retrieve information by categories, such as clothing, food, medicine, and transportation. Another set of pages lists inventions by African Americans and women, as well as by inventors from the United States and Canada, the British Isles, China, and several other nations and world regions.

ELECTRONIC DATABASES

Electronic databases usually do not have their own URLs. Instead, public, college, and university libraries subscribe to these databases, provide links to them on their Web sites, and make them available to library card holders or specified patrons. Readers can check library Web sites or ask reference librarians to check on availability.

Biography Collection Complete

EBSCO's Biography Collection Complete is a comprehensive collection of more than 177,000 full-text biographies from many different sources. The biographies cover a wide range of areas, including historical figures and persons who have made significant contributions in science and business.

Biography Resource Center

Gale's Biography Resource Center provides more than 444,000 biographies on more than 340,000 individuals, including notable figures in science, history, and other fields of endeavor. Its other features include links to related Web sites, the full text of magazine and newspaper articles, and the ability to search by a person's name or by selected biographical facts, such as years of birth or death, nationality, gender, and ethnicity.

History Reference Center

EBSCO's History Reference Center contains the full text of more than 2,400 reference books, encyclopedias, and nonfiction books from Houghton Mifflin, Lerner Publishing Group, Oxford University Press, Salem Press, and other publishers, as well as the full text of articles from 135 history periodicals. It also provides access to more than 61,100 historical documents, more than 57,000 biographies of historical figures, more than 110,200 historical photographs and maps, and more than eighty hours of historical video.

History Resource Center: U.S. and World

These two databases are produced by Gale and feature full-text articles from academic journals and periodicals, numerous primary source documents, electronic versions of reference works, topic overviews, biographies, and links to related Web sites.

Salem History

Produced by Salem Press, this database offers the full contents of the publisher's *Great Lives from History, Great Events from History*, and *Decades* sets, as well as from *Milestone Documents*, a new primary source series. Users also have access to entries from Salem's many history and social science encyclopedias.

Wilson Biographies Illustrated

Wilson Biographies Illustrated, produced by the H. W. Wilson Company, contains more than 100,000 biographies and obituaries and more than 31,000 photographs of the subjects. The database also offers the full text of more than one hundred biographical reference books published by H. W. Wilson, including *Current Biography.*

–Rebecca Kuzins

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Their Inventions. New York: Walker Books, 2003. Collection of brief chapters on inventors, written for very young readers.

Hassan, Ahmad al-, and Donald R. Hill. *Islamic Technology: An Illustrated History*. New York: Cambridge University Press, 1988. Al-Hassan tempers Hill's technical explanations. Together they produce an engaging history for the nonscientist. Bibliography, index, maps, illustrations.

Hayden, Robert C. *Nine African American Inventors*. New York: Twenty-first Century Books, 1992. Brief, simple collection of essays about African Americans whose work affects areas of contemporary living.

Heiney, Paul. *The Nuts and Bolts of Life: Willem Kolff and the Invention of the Kidney Machine*. Charleston, S.C.: The History Press, 2003. Definitive chronicle of Kolff's groundbreaking theoretical work and construction of the first dialysis machine. Emphasizes Kolff's knack for problem-solution thinking and his unshakeable belief in the medical profession's obligation to relieve suffering as his guiding premise. Written with the cooperation of Kolff.

Helden, Albert Van. *The Invention of the Telescope*. Philadelphia: American Philosophical Society, 1977. Relies on the original sources uncovered by Cornelis de Waard and published in his *De uitvinding der verrekijkers* (1906) for the most thorough discussion of the invention of the telescope. These original sources are translated and included in the appendix.

Henderson, Susan K. *African-American Inventors: Lonnie Johnson, Frederick McKinley Jones, Marjorie Stewart Joyner, Elijah McCoy, Garrett Augustus Morgan*. Mankato, Minn.: Capstone Press, 1998. Profiles key African American inventors. Photographic illustrations.

Henderson, Susan K., Stanley P. Jones, and Fred Amram. *African-American Inventors II: Bill Becoat, George Carruthers, Meredith Gourdine, Jesse Hoagland, Wanda Sigur*. Mankato, Minn.: Capstone Press, 1998. This short book is intended for high school-age readers. Provides the basic facts about the lives of five outstanding black inventors.

Henderson, Susan K. *African-American Inventors III: Patricia Bath, Philip Emeagwali, Henry Sampson, Valerie Thomas, Peter Tolliver*. Mankato, Minn.: Capstone Press, 1998. Presents a set of short biographies stressing the subjects' ability to persevere and overcome obstacles. Photographic illustrations.

Hermes, Matthew E. *Enough for One Lifetime: Wallace Carothers, Inventor of Nylon*. Washington, D.C.: American Chemical Society and the Chemical Heritage Foundation, 1996. Former DuPont researcher Matthew Hermes consulted archival records and Carothers's family, coworkers, and associates for this detailed account. Includes appendix of chemical formulas associated with Carothers's research and photographs from Carothers's relatives and friends.

Hodges, Henry. *Technology in the Ancient World*. London: Allen Lane, 1970. Organizes discussion chronologically from biblical times through the early great dynasties and empires to the early "barbarians" of the West.

Houze, Herbert G., et al. *Samuel Colt: Arms, Art, and Invention*. New Haven, Conn.: Yale University Press, 2006. A beautiful book with hundreds of photographs of firearms, the manufacturing process, paintings, the Colt family tree, and other Colt memorabilia, assembled for a special Colt exhibit at the Wadsworth Atheneum in Hartford. The book also contains extensive text, well researched and footnoted, about Samuel Colt and the business he built.

Hubbard, Geoffrey. *Cooke and Wheatstone and the Invention of the Electric Telegraph*. New York: Routledge, 2008. A new edition of a book first published in 1965, which offers a definitive account of the problematic relationship between Charles Wheatstone and his collaborator, William Fothergill Cooke, and their joint contribution to the development of telegraphy in Britain. The book endeavors to strike a judicious balance in weighing up the two men's rival claims and is more successful in that regard than most earlier accounts.

Hudson, Wade. *Book of Black Heroes: Scientists, Healers, and Inventors*. East Orange, N.J.: Just Us Books, 2003. Covers many lesser-known African American inventors. Written for a juvenile audience.

Hughes, Thomas. *A Century of Invention and Technological Enthusiasm, 1870-1970*. Chicago: University of Chicago Press, 2004. Provides comprehensive information about inventors in the United States and the roles that prominent laboratories, such as General Electric Research Laboratory, have played in their discoveries.

Huurdeman, Anton A. *The Worldwide History of Telecommunications*. Hoboken, N.J.: Wiley-IEEE, 2003. A comprehensive history of technical innovation in a number of telecommunications fields, including telegraphy, telephony, and satellite communications.

Ifrah, Georges. *The Universal History of Computing: From the Abacus to the Quantum Computer*. New

York: John Wiley & Sons, 2001. Traces the history of computing from the development of number writing up to 1654 to the modern information age. Illustrations, references, bibliography, index.

Israel, Paul. *Edison: A Life of Invention*. New York: John Wiley & Sons, 1998. Scholarly work that provides technical detail on Thomas Alva Edison's inventive work in the nineteenth century and some biographical details. Relies heavily on documents annotated and published by the Edison Papers Project in New Jersey. Illustrations, bibliography, index.

_______. *From Machine Shop to Industrial Laboratory: Telegraphy and the Changing Context of American Invention, 1820-1930*. Baltimore: The Johns Hopkins University Press, 1992. Discusses the impact of the invention of the telegraph. Bibliography, index, illustrations.

Johnson, Steven. *The Secret of Apollo: Systems Management in American and European Space Programs*. Baltimore: The Johns Hopkins University Press, 2006. A valuable resource for anyone interested in the space program, its business and management operations, or Cold War history.

Jones, Charlotte. *Accidents May Happen: Fifty Inventions Discovered by Mistake*. New York: Delacorte Books, 1996. In addition to cellophane, the author discusses Worcestershire Sauce, ice-cream floats, dynamite, and peanut brittle. Suitable for children from third to sixth grade.

Kane, Joseph Nathan. *Necessity's Child: The Story of Walter Hunt, America's Forgotten Inventor*. Jefferson, N.C.: McFarland, 1997. Posits that the story of Walter Hunt is the tragedy of an inventive genius who lacked business acumen to match his inventive prowess, resulting in many inventors gaining great wealth from his ideas. An appendix lists twenty-seven dates for patents granted to Hunt.

Keller, Julia. *Mr. Gatling's Terrible Marvel: The Gun That Changed Everything and the Misunderstood Genius Who Invented It*. New York: Viking Press, 2008. Beautifully written biography by a Pulitzer Prize-winning columnist for the *Chicago Tribune*. Much of the text puts Richard Gatling in the broader context of nineteenth century America, an age whose virtues Gatling embodied.

Kemper, Steve. *Code Name Ginger: The Story Behind Segway and Dean Kamen's Quest to Invent a New World*. Cambridge, Mass.: Harvard Business School Press, 2003. An intimate and honest first-person chronicling of the invention of the Segway PT.

Kessler, James H., J. S. Kidd, Renée A. Kidd, and Katherine A. Morin. *Distinguished African American Scientists of the Twentieth Century*. Phoenix, Ariz.: Oryx Press, 1996. Encyclopedic book covers the lives and accomplishments of one hundred African American scientists and inventors. Full of biographical data, arranged alphabetically and including a photograph of each profiled person. Written for young readers in clear and rather plain language.

Klein, Aaron E., and Cynthia L. Klein. *The Better Mousetrap: A Miscellany of Gadgets, Labor-Saving Devices, and Inventions That Intrigue*. New York: Beaufort Books, 1982. Provides a context for discussion of inventions by combining a history of progress in the United States with accounts of inventions at different periods throughout the country's history. Categories of inventions include farm equipment, factory machines, transportation items, scientific inventions, construction tools, household items, printing equipment, sewing machines, medical and dental equipment, firearms, clocks, and musical instruments.

Klemm, Friedrich. *A History of Western Technology*. Translated by Dorothea Waley Singer. London: Allen & Unwin, 1959. Traces the development of technology from the Greco-Roman world through twentieth century America. Includes some lesser-known inventions.

Knapp, Zondra. *Super Invention Fair Projects*. Los Angeles: Lowell House Juvenile, 2000. After identifying characteristics of great inventors, Knapp outlines steps in getting started on and planning a project, discusses research procedures and design materials, and ends with a discussion of patents and trademarks. Appendix contains a list of invention contests and competitions in the United States.

Korman, Richard. *The Goodyear Story: An Inventor's Obsession and the Struggle for a Rubber Monopoly*. San Francisco: Encounter Books, 2002. A biography about the man who created one of the most important industrial products in history.

Kranzberg, Melvin, and Carroll W. Pursell, Jr., eds. *The Emergence of Modern Industrial Society*. Vol. 1 in *Technology in Western Civilization*. New York: Oxford University Press, 1967. Tells the story of the development of technology in Western civilization from the beginning of mankind through 1900.

_______. *Technology in the Twentieth Century*. New York: Oxford University Press, 1967. Vol. 2 in *Technology in Western Civilization*. New York: Oxford

University Press, 1967. This volume details the development of technology during the first half of the twentieth century.

Kranzberg, Melvin, and William H. Davenport, eds. *Technology and Culture: An Anthology*. New York: Schocken Books, 1972. A collection of essays intended to encourage study of technological development and how it relates to culture and society. Four parts cover technology and society, technology and the humanities, humans and machines, and invention and innovation.

Landau, Elaine. *The History of Everyday Life*. Minneapolis, Minn.: Twenty-first Century Books, 2005. Written for young readers, this book discusses indoor plumbing, household appliances, and central heating, among other topics.

Laurenza, Domenico, Mario Tadei, and Edoardo Zanon. *Leonardo's Machines: Da Vinci's Inventions Revealed*. Cincinnati, Ohio: David & Charles, 2006. Using detailed diagrams and color illustrations, the authors show how Leonardo's inventions could have been constructed, how they would have functioned, and how they had an impact on subsequent inventors and inventions.

Lay, Maxwell G. *Ways of the World: A History of the World's Roads and of the Vehicles That Used Them*. New Brunswick, N.J.: Rutgers University Press, 1992. Engaging, comprehensive account of transportation and roadways. Accessible to general readers as well as professional engineers. Includes extensive notes, bibliography, index.

Lindsay, David. *House of Invention: The Secret Life of Everyday Products*. New York: Lyons Press, 2000. Organized according to location in a house, this lively and readable book introduces tidbits of information about inventors of everyday products found in the bathroom (disposable razor, Vaseline, hair straightener), the kitchen (frozen food, blender, breakfast cereal), the foyer (intercom, bank notes, locks and keys), the office (Musak, pencil), the garage (intermittent windshield wiper, standard screw thread), the family room (television, exercise machine, Solitaire), and the bedroom (brassiere, condom).

Loewe, Michael, and Edward L. Shaughnessy. *The Cambridge History of Ancient China: From the Origins of Civilization to 221 B.C.* New York: Cambridge University Press, 1999. Covers pre-imperial China in the Shang, Western Zhou, Spring and Autumn, and Warring States periods. Essays written on archaeology, agriculture, language and writing, art and architecture, and classical philosophy preceding the age of Confucius.

Lord, John. *Memoir of John Kay of Bury, Inventor of the Fly-Shuttle, with a Review of the Textile Trade and Manufacture from Earliest Times*. Rochdale, Manchester, England: J. Clegg, 1903. A celebratory account of Kay's allegedly revolutionary achievement, heavily dependent on Thomas Sutcliffe's propagandizing, which provided the source of most twentieth century biographical accounts.

Macdonald, Anne L. *Feminine Ingenuity: How Women Inventors Changed America*. New York: Ballantine Books, 1992. Traces the history of female inventors from early U.S. history through the twentieth century. Contrasts the kinds of inventions that women made early on with later inventions considered "beyond woman's sphere." Cites the struggles, the small victories in women's rights, and the setbacks experienced before some sense of gender equity was achieved. Details the process of obtaining patents. Appendix lists patents of inventors cited in the text. Bibliography.

McGrayne, Sharon Bertsch. *Nobel Prize Women in Science: Their Lives, Struggles, and Momentous Discoveries*. Secaucus, N.J.: Carol, 1993. Very readable and well-researched biographies of fourteen female scientists who overcame gender discrimination as both students and researchers to accomplish groundbreaking scientific work. Illustrated. Notes and index.

Mackenzie, Donald. *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*. Cambridge, Mass.: MIT Press, 1990. Based on archival documents and interviews with those working in the field. Author discusses the relevant technology and explains it in a nonmathematical way. Focuses on social and historical contexts.

McKinley, Burt. *African-American Inventors*. Portland, Oreg.: National Book Company, 2000. Short studies on black inventors that includes bibliographic references.

Maclaurin, William Rupert. *Invention and Innovation in the Radio Industry*. New York: Arno Press, 1971. Surveys technological advancements in the radio industry. Explores the causes for these developments and examines the impact of the new medium on American society.

Maier, Pauline, Merritt Roe Smith, Alexander Keyssar, and Daniel J. Kevles. *Inventing America: A History of the United States*. New York: W. W. Norton, 2003. Innovation is the basic theme of this revisionist account. Illustrated, with appendixes and index.

Margulis, Lynn, and Eduardo Punset, eds. *Mind, Life, and Universe: Conversations with Great Scientists of Our Time*. White River Junction, Vt.: Chelsea Green, 2007. The authors interviewed thirty-six scientists about their thoughts and ideas regarding some of the most important concepts influencing their fields today. An index and bibliographical references are included.

Molella, Arthur, and Joyce Bedi, eds. *Inventing for the Environment*. Lemelson Center Studies in Invention and Innovation. Cambridge, Mass.: MIT Press, 2003. Describes the ways in which innovations, broadly considered, affect the environment and public health.

Moore, A. D. *Invention, Discovery, and Creativity*. Garden City, N.Y.: Doubleday, 1969. Delves into the qualities and traits that promote invention and discovery, focusing in particular on characteristics of creative people. Offers tips for would-be inventors.

Morgan, Michael Hamilton. *Lost History: The Enduring Legacy of Muslim Scientists, Thinkers, and Artists*. Washington, D.C.: National Geographic, 2007. Morgan includes biographies of a variety of Muslim figures whose works would leave a mark on Western endeavors in fields as diverse as medicine, astronomy, and mathematics.

Mosley, Thomas E., Jr. *Marketing Your Invention*. Dover, N.H.: Upstart, 1992. Points out the difficulty, expense, and dangers of marketing an invention. Identifies characteristics of successful new products, discusses licensing, and suggests ten temperaments and habits that lead to "invention suicide," among which are paranoia, greed, impatience, procrastination, and a sense of omnipotence.

Nachmansohn, David. *German-Jewish Pioneers in Science, 1900-1930: Highlights in Atomic Physics, Chemistry, and Biochemistry*. New York: Springer-Verlag, 1979. While some familiar names appear, the book treats some of the amazing scientific discoveries of a number of lesser-known scientists in chemistry, biochemistry, and physiology in particular. Provides a historical background and ends with a chapter on the worldwide effects on biochemistry due to persecution and subsequent flight from Germany.

Naughton, John. *A Brief History of the Future: From Radio Days to Internet Years in a Lifetime*. Woodstock, N.Y.: Overlook Press, 2000. Surveys the great minds who contributed to the birth of the Internet. Glossary, index.

Nye, Mary Jo, ed. *The Cambridge History of Science*. New York: Cambridge University Press, 2003. An acclaimed series and international standard in the history of science.

Oleksy, Walter. *Hispanic-American Scientists*. New York: Facts On File, 1998. Brief biographical sketches with a few photos and a useful chronology.

Owen, David. *Copies in Seconds: How a Lone Inventor and an Unknown Company Created the Biggest Communication Breakthrough Since Gutenberg—Chester Carlson and the Birth of the Xerox Machine*. New York: Simon & Schuster, 2004. A lively account of Carlson's life and work based on interviews with his widow and previously inaccessible manuscripts.

Pacey, Arnold. *The Maze of Ingenuity: Ideas and Idealism in the Development of Technology*. New York: Holmes & Meier, 1975. Divides discussion into two parts: a chronological history of technology and ideas, and technological trends. An introduction defines concepts and terms.

Petroski, Henry. *The Evolution of Useful Things*. New York: Alfred A. Knopf, 1992. Discusses the invention of small items such as forks, paper clips, and small tools.

Pilato, Denise E. *The Retrieval of a Legacy: Nineteenth Century American Women Inventors*. Westport, Conn.: Praeger, 2000. Dedicated exclusively to female inventors of the nineteenth century, this work focuses on technological invention. Notes, bibliography, index.

Platt, Richard, *Eureka! Great Inventions and How They Happened*. Boston: Kingfisher, 2003. Platt examines the circumstances in which some of the world's best-known inventions were conceived and discusses the genius of their inventors.

_______. *Smithsonian Visual Timeline of Inventions*. New York: Dorling Kindersley, 1994. Provides chronologically ordered pictures and descriptions of more than 250 inventors and more than 400 of their inventions in addition to an illustrated time line of world events.

Pritchard, J. Laurence. *Sir George Cayley: The Inventor of the Aeroplane*. New York: Horizon Press, 1962. The first full biography of George Cayley, the "father of aviation." Chapter notes, index.

Purcell, Carroll, ed. *A Hammer in Their Hands: A Documentary History of Technology and the African American Experience*. Cambridge, Mass.: MIT Press, 2005. This scholarly publication provides a collection of primary sources that document African American technological achievements.

Ravage, Barbara. *George Westinghouse: A Genius for*

Invention. Austin, Tex.: Raintree Steck-Vaughn, 1997. An account of Westinghouse's life and inventions written with an adolescent audience in mind. A pioneer of the electrical industry, Westinghouse was a major rival of Thomas Alva Edison.

Rees, Fran. *Johannes Gutenberg: Inventor of the Printing Press*. Minneapolis, Minn: Compass Point Books, 2006. Offers a brief history of the printing press. Written in a fluid style, the book is aimed at young readers. Includes glossary, illustrations, maps, bibliography, and additional resources.

Reid, T. R. *Chip: How Two Americans Invented the Microchip and Launched a Revolution*. New York: Random House, 2001. A journalist's fashioning of the independent and nearly simultaneous invention of the microchip, told as a suspense thriller with all technical questions reduced to layperson's language. A masterpiece of science reporting by a nonscientist.

Reiser, Stanley Joel. *Medicine and the Reign of Technology*. New York: Cambridge University Press, 1981. Landmark treatise that lays out the fundamental arguments and issues of the new field of biomedical engineering. Investigates the relationship between revolutionary medical procedures and quality-of-life issues, medical costs, and religious biases. Thoughtful, provocative, and careful to avoid taking sides. Extensive bibliography.

Richardson, Jacques G., ed. *Windows on Creativity and Invention*. Mt. Airy, Md.: Lomond, 1988. The fifth of a series of UNESCO-generated books, this five-part volume contains twenty-five essays related to creativity and invention. Topics include the natural sciences, art, music, and the creative process.

Rijper, Els. *Kodachrome: The American Invention of Our World, 1939-1959*. New York: Delano Greenidge Editions, 2002. More than two hundred photos, originally taken with black-and-white film, are displayed with Kodachrome colorization. The book contains perspectives of American cities, personalities, sports, fashion, politics, and culture of the mid-twentieth century.

Romano, Frank J. *Machine Writing and Typesetting: The Story of Sholes and Mergenthaler and the Invention of the Typewriter and the Linotype*. Salem, N.H.: GAMA, 1986. Linking Ottmar Mergenthaler's Linotype with the concurrent invention of the typewriter by Christopher Latham Sholes supplies a larger context of the development of print technology at the end of the nineteenth century.

Rubik, Ernö, et al. *Rubik's Cubic Compendium*. New York: Oxford University Press, 1987. A collection of essays and exercises related to the Rubik's cube. One chapter by Rubik himself relates the events that led to his perfecting the cube.

Rubin, Susan Goldman. *Toilets, Toasters, Telephones: The How and Why of Everyday Objects*. New York: Harcourt, 1998. Although this is classified as a juvenile book, the history and description of eleven types of common household items would appeal to adults as well. Ample bibliography.

Rudy, Lisa Jo. *The Ben Franklin Book of Easy and Incredible Experiments*. Hoboken, N.J.: John Wiley & Sons, 1995. Includes a brief biographical sketch of Benjamin Franklin and provides interesting juvenile experiments involving weather, electricity, music, printing, light, and sound. Glossary and index.

Schatzkin, Paul. *The Boy Who Invented Television: A Story of Inspiration, Persistence, and Quiet Passion*. Vancouver, B.C.: Tanglewood Books, 2004. Biography that provides details of Philo T. Farnsworth's life, his inventive genius, and his challenges in life. Covers the technological developments that Farnsworth made, the funding he received for various television experiments, and his struggle for patent protection. Also explores how isolated inventors were fast being replaced by funded corporate laboratories during the 1930's. Bibliography, index.

Schwartz, Evan I. *Juice: The Creative Fuel That Drives World-Class Inventors*. Boston: Harvard Business School Press, 2004. A theoretical look at the process of inventing.

Shagena, Jack L. *Who Really Invented the Steamboat? Fulton's "Clermont" Coup*. Amherst, N.Y.: Humanity Books, 2004. Highly readable account of the work of several inventors and thinkers. Shagena gives useful background on patent law and steam power and carefully assesses the claims to primacy of eight inventors.

Shectman, Jonathan. *Groundbreaking Scientific Experiments, Inventions, and Discoveries of the Eighteenth Century*. Westport, Conn.: Greenwood Press, 2003. The introduction gives an overview of the eighteenth century interest in science; several essays discuss scientific discoveries, applications, and investigations to provide background on the impact of scientific advances, such as the Leiden jar, on social and political history.

Shulman, Seth. *Unlocking the Sky: Glenn Hammond Curtiss and the Race to Invent the Airplane*. New York: HarperCollins, 2002. The author vividly describes the legal wrangling between the Wright brothers, who laid claim to all technology related to powered flight, and Curtiss, who represented all of the other aircraft pioneers who felt that the Wrights were claiming innovations developed by others. A very readable account, the book ends with Curtiss's eventual triumph over the Wrights when he acquired their aircraft company.

Singer, Charles Joseph, E. J. Holmyard, and A. R. Holt, eds. *From Early Times to the Fall of Ancient Empires*. Vol. 1 in *A History of Technology*. Oxford, England: Clarendon Press, 1954. A collection of essays treats seven sections of the period covered: basic social factors, food collecting, domestic activities, specializing industries, utilization of metals, transportation, and preparation for science.

_______. *The Mediterranean Civilization and the Middle Ages, c. 700 B.C. to c. A.D. 1500*. Vol. 2 in *A History of Technology*. Oxford, England: Clarendon Press, 1956. Essays discuss mining, metallurgy, agriculture, food and drink, leather, spinning and weaving, furniture, ceramics, glass and glazes, and prescientific chemistry.

_______. *From the Renaissance to the Industrial Revolution*. Vol. 3 in *A History of Technology*. Oxford, England: Clarendon Press, 1957. Follows technological progress for this time period by focusing on five areas: primary production (food and drink, metallurgy and assaying, coal mining and utilization, windmills), manufacturing (tradesmen's tools, farm tools, vehicles and harnesses, spinning and weaving, and glass), material civilization (building construction, town planning, land drainage and reclamation, machines and mechanisms, military technology, printing), communications (bridges, canals, shipbuilding, cartography, and navigation), and approaches to science (calendars, precision instruments, mechanical timekeepers, chemical inventions).

_______. *The Industrial Revolution, c. 1750-c. 1850*. Vol. 4 in *A History of Technology*. Oxford, England: Clarendon Press, 1958. Divides the discussion into six areas: primary production (agricultural inventions and techniques, fish preservation, ferrous and nonferrous metal extraction), energy (steam engines, watermills), manufacture, static engineering (building and civil engineering, sanitation engineering), communication, and the scientific basis of technology.

_______. *The Late Nineteenth Century*. Vol. 5 in *A History of Technology*. Oxford, England: Clarendon Press, 1958. Eight sections outline technological developments in primary production, engines, electricity, chemical industry, transport, civil engineering, manufacturing, and technology at the threshold of the twentieth century. Includes a discussion of the consequences of technology.

Sluby, Patricia Carter. *The Inventive Spirit of African Americans: Patented Ingenuity*. Westport, Conn.: Praeger, 2004. Using a historical approach beginning with African creations, the book moves on to inventions made during the period of slavery in the United States, treating both enslaved and free persons of color. Notes inventions by African Americans that were important to the war effort during World War I and the "balm" that the Civil Rights era afforded African Americans in terms of being able to demonstrate their skills and creativity. A lengthy appendix contains a roster of African American patentees from 1821 through the mid-1990's.

Spangenburg, Ray, and Kit Moser. *African Americans in Science, Math, and Invention*. New York: Facts On File, 2003. Outlines the lives of 160 African American scientists since 1731, highlighting not only the challenges and difficulties the subjects encountered in their scientific pursuits but also the barriers to their formal education and training. Includes a bibliography, special categorical index, and black-and-white photographs.

Stableford, Brian. *Science Fact and Science Fiction: An Encyclopedia*. New York: Routledge, 2006. Focusing on the nineteenth century to the present, Stableford examines how science has influenced science fiction and vice versa.

Sullivan, Otha Richard, and James Haskins. *African American Women Scientists and Inventors*. New York: John Wiley & Sons, 2002. A simple, straightforward presentation of African American women who have influenced science and technology. Written for a juvenile audience.

Sutcliffe, Andrea. *Steam: The Untold Story of America's First Great Invention*. New York: Palgrave Macmillan, 2004. Traces the development of steam power and its effects on American society.

Swedin, Eric C., and David L. Ferro. *Computers: The Life Story of a Technology*. Westport, Conn.: Greenwood Press, 2005. Provides a succinct and readable overview, from early calculators to modern computers. Illustrations, bibliography, index.

Tang, Joyce. *Scientific Pioneers: Women Succeeding in Science*. Lanham, Md.: University Press of America, 2006. Analyzes the lives and careers of ten female scientists in the context of personal, cultural, political, and economic factors. Bibliography, index.

Taylor, Nick. *Laser: The Inventor, the Nobel Laureate, and the Thirty-Year Patent War*. New York: Simon & Schuster, 2000. A 304-page description of the thirty-year patent battle over the invention of the laser.

Thompson, Holland. *The Age of Invention: A Chronicle of Mechanical Conquest*. New Haven, Conn.: Yale University Press, 1921. One volume in a series devoted to American life, history, and progress. Includes an ample bibliography as well as photographs and illustrations.

Thomson, Janet. *The Scot Who Lit the World: The Story of William Murdoch, Inventor of Gas Lighting*. Glasgow, Scotland: Janet Thomson, 2003. Concise and very readable account of Murdock's life and creativity—not only his work on gas lighting but also his many other contributions to the advancement of technology and society. A chapter is devoted to some of his many lesser-known inventions. Bibliography, index, tourist guide.

Time. *Great Inventions: Geniuses and Gizmos—Innovation in Our Time*. New York: Time Books, 2003. Organizes discussion of dozens of inventions according to function: how we explore, move, communicate, record, eat, live, think, work, and play.

Tracy, Kathleen. *Willem Kolff and the Invention of the Dialysis Machine*. Bear, Del.: Mitchell Lane, 2002. Geared for high school readers, Tracy's work offers a clear and helpfully illustrated explanation of Kolff's original design and the evolution of his basic theory into the dialysis machines of today. Quite a heroic depiction of Kolff; stresses the difficult wartime conditions under which he worked.

Trevithick, Francis. *Life of Richard Trevithick, with an Account of His Invention*. 2 vols. Whitefish, Mont.: Kessinger, 2006. A reprint of the highly detailed justificatory biography written by Trevithick's eldest son, first published in 1872, which provided the primary source for later synoptic biographies.

Usher, Abbot Payson. *A History of Mechanical Inventions*. Rev. ed. New York: Dover, 1954. Places technology in the context of economic history and analyzes social change over time. Discusses ten categories of inventions from 150 B.C. to the early twentieth century.

Van Dulken, Stephen. *American Inventions: A History of Curious, Extraordinary, and Just Plain Useful Patents*. New York: New York University Press, 2004. Looks at the world of patents and how the products they register have helped to create the American Dream. In an easy, conversational style, Van Dulken discusses dozens of inventions, especially those in the areas of children's devices, sports equipment, entertainment, health, the home, and the office.

Vare, Ethlie Ann, and Greg Ptacek. *Patently Female: From AZT to TV Dinners—Stories of Women Inventors and Their Breakthrough Discoveries*. New York: John Wiley & Sons, 2002. Includes brief, interview-based articles on women inventors, including what it was like to be a female scientist in the mid-twentieth century. Photographs, time lines, list of organizations and online resources related to female inventors, index.

Webster, Raymond B. *African American Firsts in Science and Technology*. Foreword by Wesley L. Harris. Detroit, Mich.: Gale, 1999. These brief, chronologically ordered biographies—about twelve hundred of them—offer a broad survey of African American "firsts."

Weightman, Gavin. *Signor Marconi's Magic Box: The Most Remarkable Invention of the Nineteenth Century and the Amateur Inventor Whose Genius Sparked a Revolution*. Cambridge, Mass.: Da Capo Press, 2003. A well-told narrative useful for those interested in the history of radio.

Williams, Michael R. *A History of Computing Technology*. 2d ed. Los Alamitos, Calif.: IEEE Computer Society Press, 1997. Contains chapters describing the various technologies and machines that contributed to the development of the modern computer. Illustrations, further reading lists, index.

Williams, Trevor I. *The History of Invention*. New York: Facts On File, 1987. Arranged in five parts, this work moves from the beginning of civilization and the agricultural revolution to paper and printing; traces the beginning of mechanization and the birth of the chemical industry; and then moves on to the modern era with its changing patterns and needs. Discusses the post-World War II era and information technology. Biographical dictionary, bibliography, index.

_______, ed. *The Twentieth Century, c. 1900-c. 1950*. Part 1. Vol. 6 in *A History of Technology*. Oxford, England: Clarendon Press, 1978. Continues the work of Singer, et al., above. Puts twentieth century technological developments in the wider world context. Discusses sources of innovation, economics of technology, management, trade unions, role of government, education in industrialized societies, fossil fuels, natural sources of power, and atomic energy.

_______. *The Twentieth Century, c. 1900-c. 1950*. Part 2.

Vol. 7 in *A History of Technology*. Oxford, England: Clarendon Press, 1978. Continues part 1 with accounts of the development of the world transport market, road vehicles, ships and shipbuilding, railways, aircraft, navigation equipment, space technology, civil engineering projects, land reclamation, building and architecture, town planning, electrical engineering, food technology, and other categories of invention that affect quality of life.

Wilson, Mitchell. *American Science and Invention: A Pictorial History*. New York: Simon & Schuster, 1954. A large volume that relies on period illustrations and photographs to describe the course of American invention.

Windelspecht, Michael. *Groundbreaking Scientific Experiments, Inventions, and Discoveries of the Nineteenth Century*. Westport, Conn.: Greenwood, 2003. A book in a series spanning the modern centuries. Describes more than sixty major inventions of the nineteenth century.

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